MAGNEFORCE SOFTWARE SYSTEMS, INC.

BLDC

Installation Manual and User Guide

BLDC Installation Manual & User Guide

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Chapter

1

About BLDC

BLDC is a brushless DC simulation environment. It is designed for quick learning, ease of use, and the ability to provide powerful results. The goal of this software is to allow the designer to experiment with such things as materials, geometries and winding configurations, without ever having to build a prototype. The results provided by BLDC are as good as test data but achievable in a much shorter time frame and at lower cost. As you will see, BLDC provides parameterized results such as voltages, currents, torque and power together with more esoteric results such as flux, iron loss and current density.

BLDC is divided into five distinct panels:

- **Settings Panel**
  This panel allows you to examine and adjust the material properties of all magnetic materials loaded into the MagneForce suite of simulators. Here you will find magnetic curves for both steel and permanent magnet materials. You can also add new materials to the MagneForce suite of simulators. This panel also contains global software parameters that control such things as mesh density.

- **Design Panel**
  In this panel you will define the physical dimensions of the machine as well as choose the armature and field materials plus define the windings. Whenever you create or open a new or existing project, you will first be placed at the design panel.

- **Run Panel**
  Once you have selected and described a machine, the run panel is used to select the type of simulation plus initiate the simulation process. Choices of simulation include parameter, load, fault study, asymmetrical or special. Once a type is selected, you may then select the number of load points, associated parameters and begin the simulation.

- **Results Panel**
  Upon simulation completion, the performance results panel is used to view the various parameterized output. Output ranges from the open circuit machine parameters up to and including the complete set of machine and load voltage and current waveforms, as well as torque and power.

- **Field Explorer Panel**
  The field explorer panel is used to display the machine geometry, finite element mesh, magnetic field density, current density and iron loss density. These fields can be displayed for any of the load solution points.

BLDC allows you to create a new project from a pre-defined list, modify the project and then save it under a different name. In this way, you can work with several design variations simultaneously. Projects can be opened and saved at any time and the number of total projects is limited only to the size of your hard disk drive.

Chapter

2

Minimum System Requirements

BLDC is a powerful finite element based electromagnetic modeling software package, and as such it performs a large amount of mathematical computations. The two largest factors affecting system performance, in software of this type, are the processor speed and available memory. Often times, users can gain a significant performance enhancement simply by adding RAM. Accordingly, MagneForce recommends you equip your computer with the maximum practical amount of RAM.

Pentium III
Windows NT, 2000 or XP
256 MB RAM
200 MB free hard drive space
SVGA monitor operating at 1024 X 768 resolution or
800 X 600 resolution if using small fonts
Mouse pointing device

Chapter

3

Installing BLDC

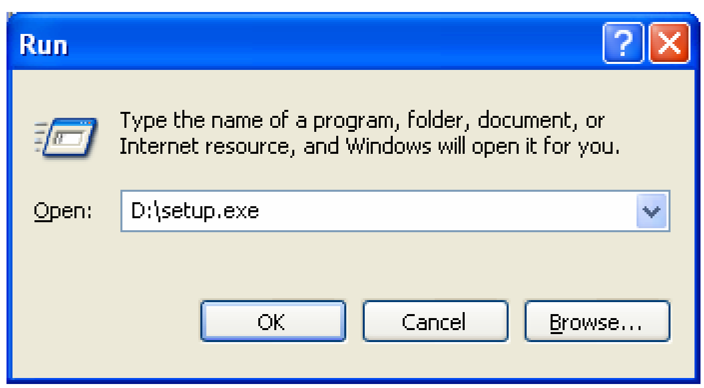
Installing BLDC is an easy multi-part procedure. First, the software is installed. Secondly, the license.txt file must be copied to the appropriate directory. And finally, the hardware key must be attached.

- Close all applications. It is best to perform the installation without any other applications open.

- Insert the MagneForce CD-ROM disk into your computer's CD-ROM drive.

- From the START menu, choose the RUN command

- Type into the RUN command dialog box D:\SETUP.EXE, where D: is the name of your computer's hard disk drive.



- Follow the onscreen instructions. You will be allowed to change the software installation directory as well as the program folder, if desired.

- Depending upon your version of Windows, you may be instructed to re-boot your computer and to re-run the installation routine. Also some versions of Windows do not completely close the installation DOS window. If this is the case, close the window manually by clicking the X in the upper right hand corner.

- After installation completion, copy the LICENSE.TXT file to the C:\PROGRAM FILES\MAGNEFORCE subdirectory if you accepted the default installation directory from step 4 above. If you modified this directory structure, the LICENSE.TXT file must be copied into the MAGNEFORCE directory, that is the directory containing BLDC.EXE. The LICENSE.TXT file unlocks and allows the appropriate simulators to run. If you do not have a LICENSE.TXT file, please contact MagneForce.

- Attach the security key, supplied with the software. The security key will either be the parallel port variety or the USB variety. In the case of the USB variety your computer will perform a brief installation routine the first time that the key is inserted in each USB port

- Congratulations. Software installation is now complete.

Chapter

4

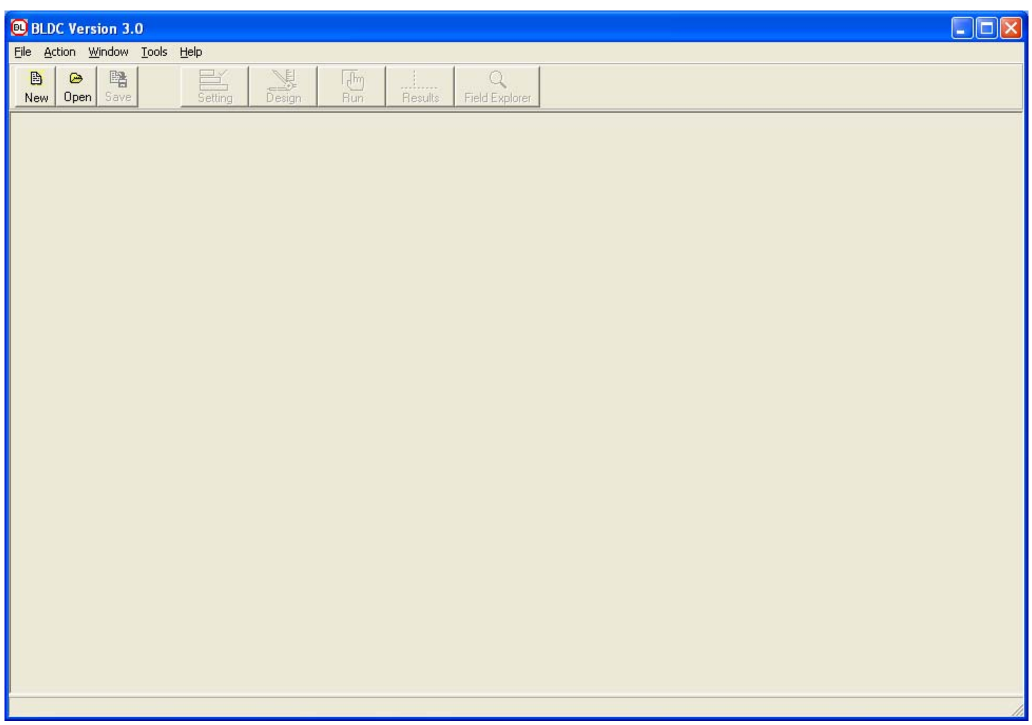
Starting BLDC

BLDC is written to follow normal Windows operating standards and conventions.

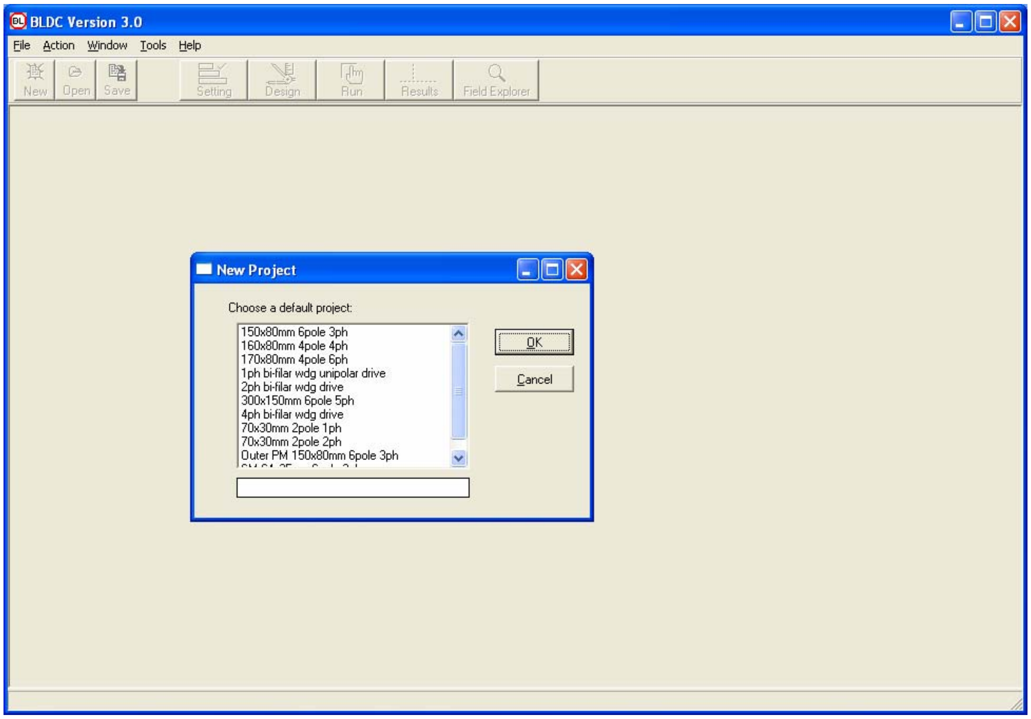
To start BLDC,

Click the START button

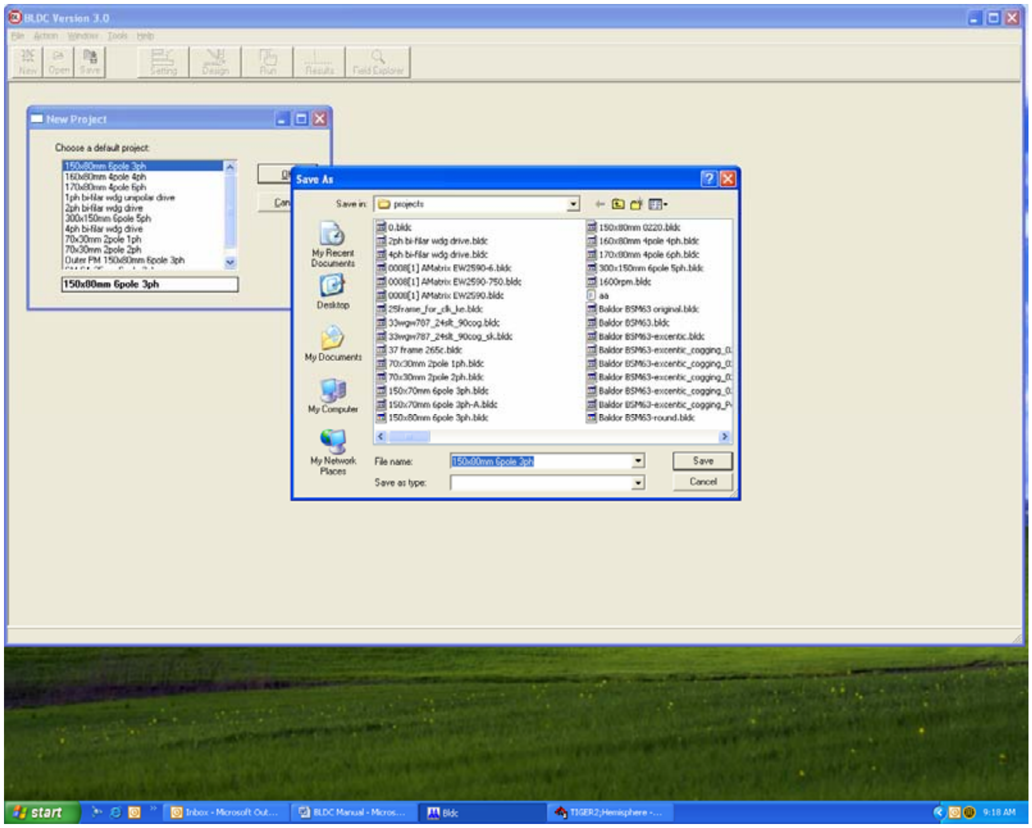
- Go to PROGRAMS
- Click on MAGNEFORCE SIMULATION SUITE
- Click on BLDC
- The following screen is displayed



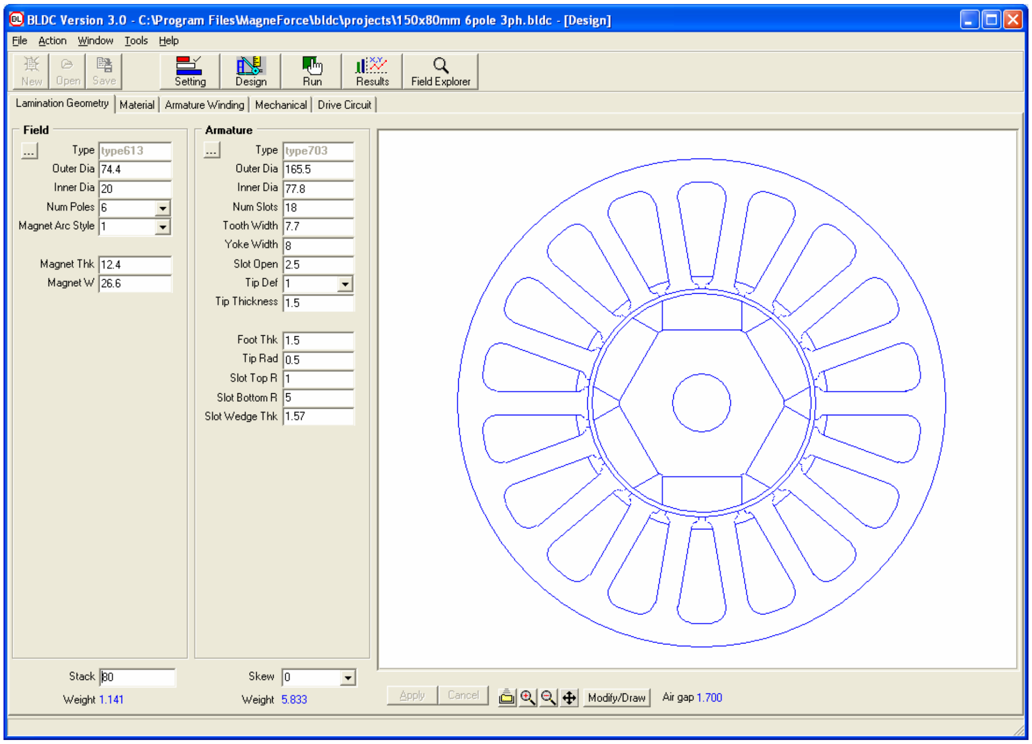
If this is the first time you have started BLDC or you have not saved any projects, your only option will be to select NEW from the PANEL TOOLBAR. Doing so will give you a list of default projects from which to choose.



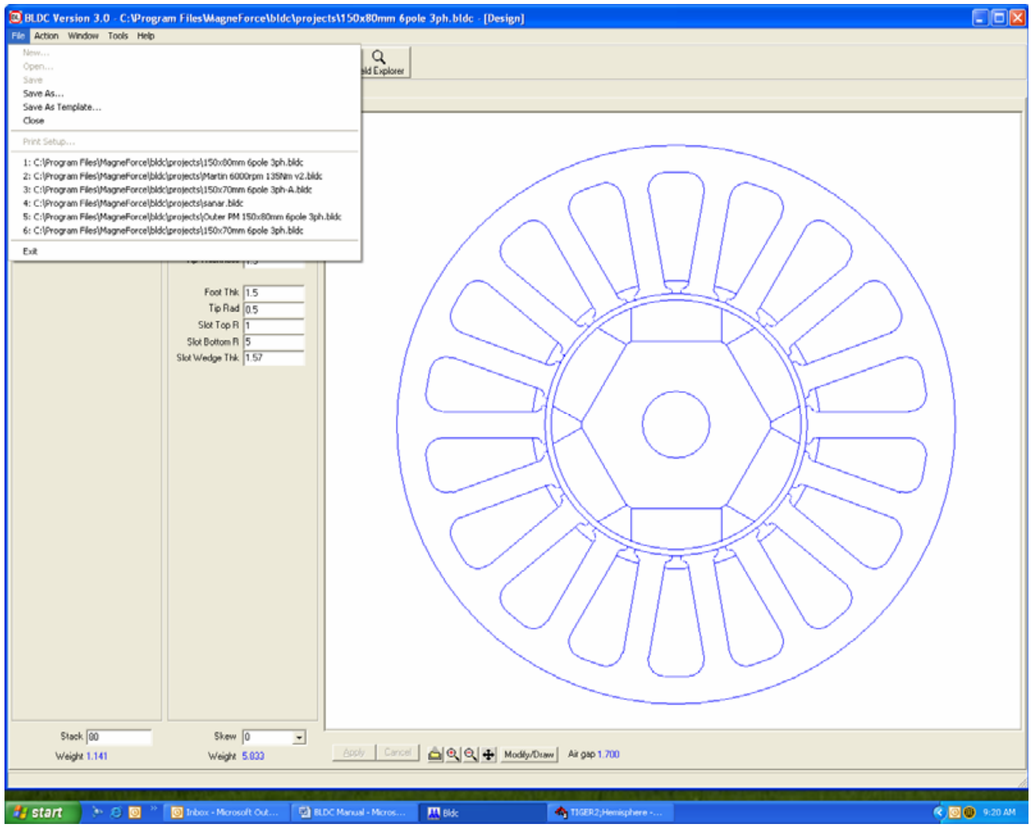
Choose a project that most closely resembles your desired project. Once a choice has been made you will be prompted to save the project under a new name. At this point you may choose to save the project to any folder you wish. The default project location is C:\PROGRAM FILES\MAGNEFORCE\BLDC\PROJECTS.



After Clicking SAVE, your newly named project will be opened and you will be placed at the DESIGN panel.



A listing of recently opened projects is available under the File menu. Click FILE then scroll down the option list and highlight and click the desired project.


BLDC Version 3.0 - C:\Program Files\MagneForce\bldc\projects\150x80mm 6pole 3ph.bldc - [Design]
File Action Window Tools Help
Save As...
Save As Template...
Close
1: C:\Program Files\MagneForce\bldc\projects\150x80mm 6pole 3ph.bldc
2: C:\Program Files\MagneForce\bldc\projects\Martin 6000rpm 135Nm v2.bldc
3: C:\Program Files\MagneForce\bldc\projects\150x70mm 6pole 3ph-A.bldc
4: C:\Program Files\MagneForce\bldc\projects\sanar.bldc
5: C:\Program Files\MagneForce\bldc\projects\Outer PM 150x80mm 6pole 3ph.bldc
6: C:\Program Files\MagneForce\bldc\projects\150x70mm 6pole 3ph.bldc
Exit
Foot Thk 1.5
Tip Rad 0.5
Slot Top R 1
Slot Bottom R 5
Slot Wedge Thk 1.57
Stack 80
Weight 1.141
Skew 0
Weight 5.833
Apply Cancel
Modify/Draw
Air gap 1.700

Chapter

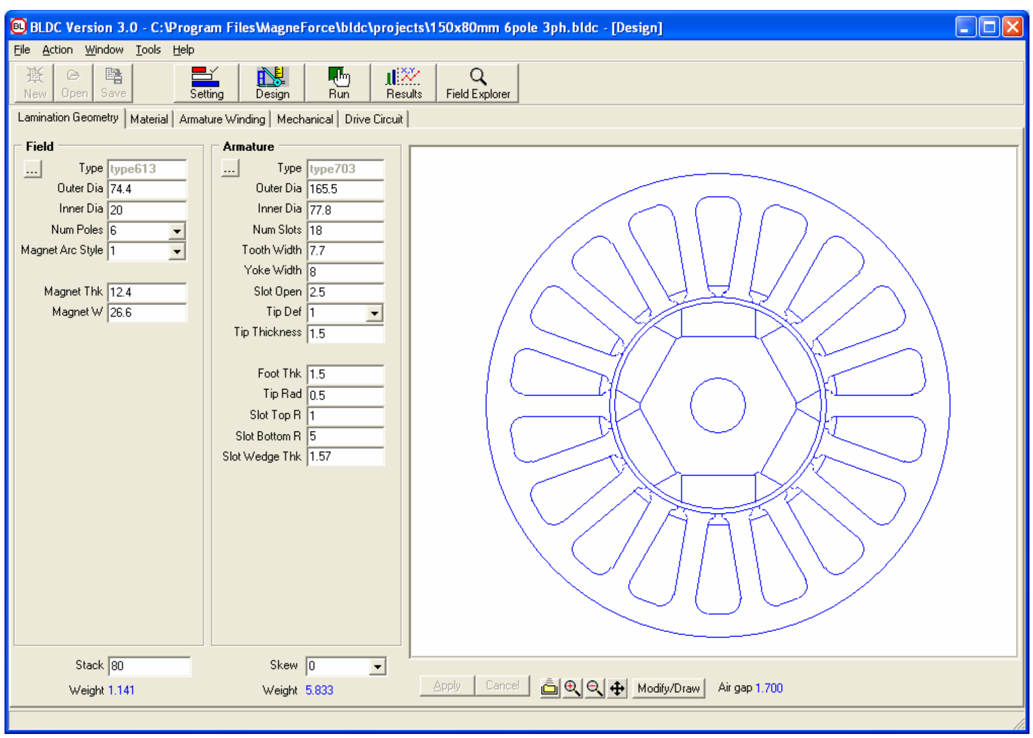
5

The Design Panel

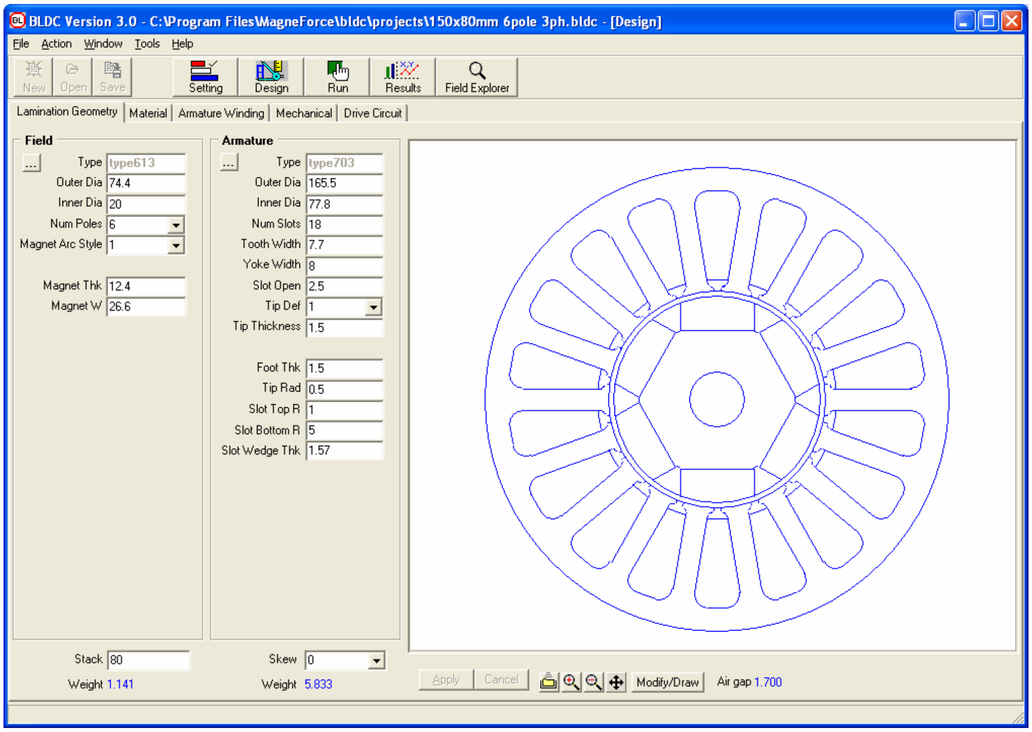
In this panel, you will define the physical dimensions of the machine as well as select the armature and field materials plus define the windings. Whenever you create or open a new or existing project, you will first be placed at the design panel.

This panel has five tabs:

- Lamination Geometry Tab.
- Material Tab.
- Armature Winding Tab.
- Mechanical Tab.
- Drive Circuit Tab.



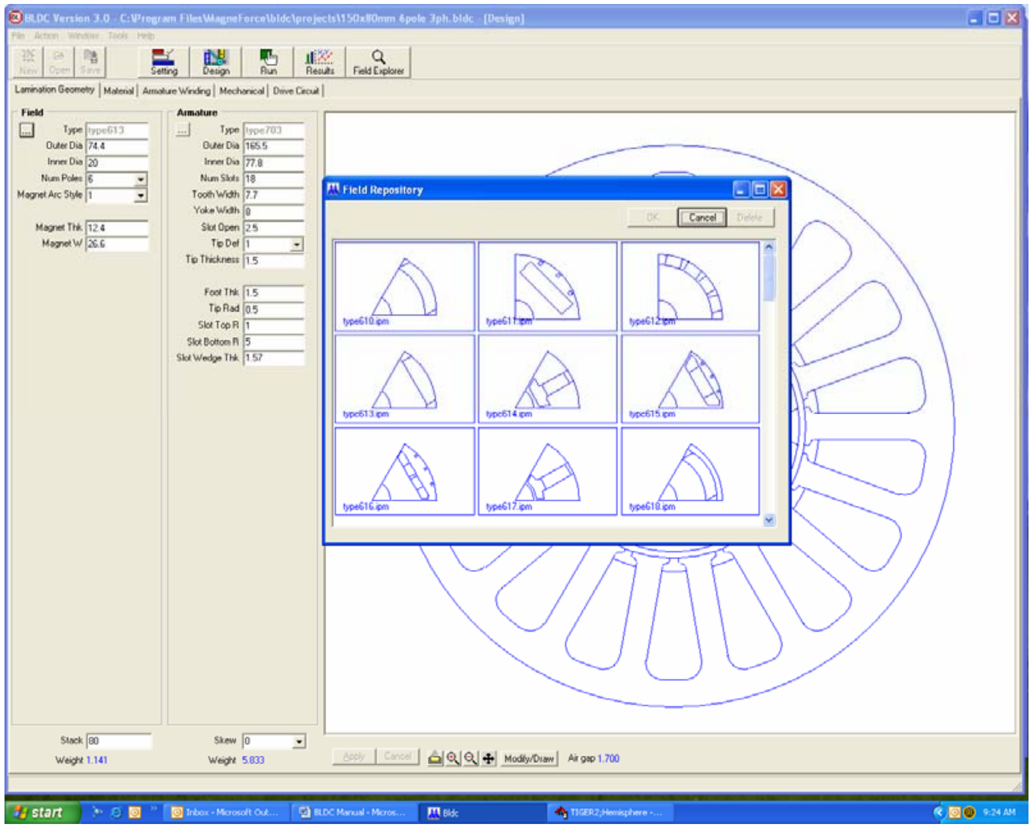
LAMINATION GEOMETRY TAB



This tab has sections on the left that describe the physical dimensions of the field, armature and machine in general. On the right, is a cross sectional drawing of the machine.

The field parameters will vary depending upon the exact rotor geometry chosen. The following is for a type 613 permanent magnet rotor:

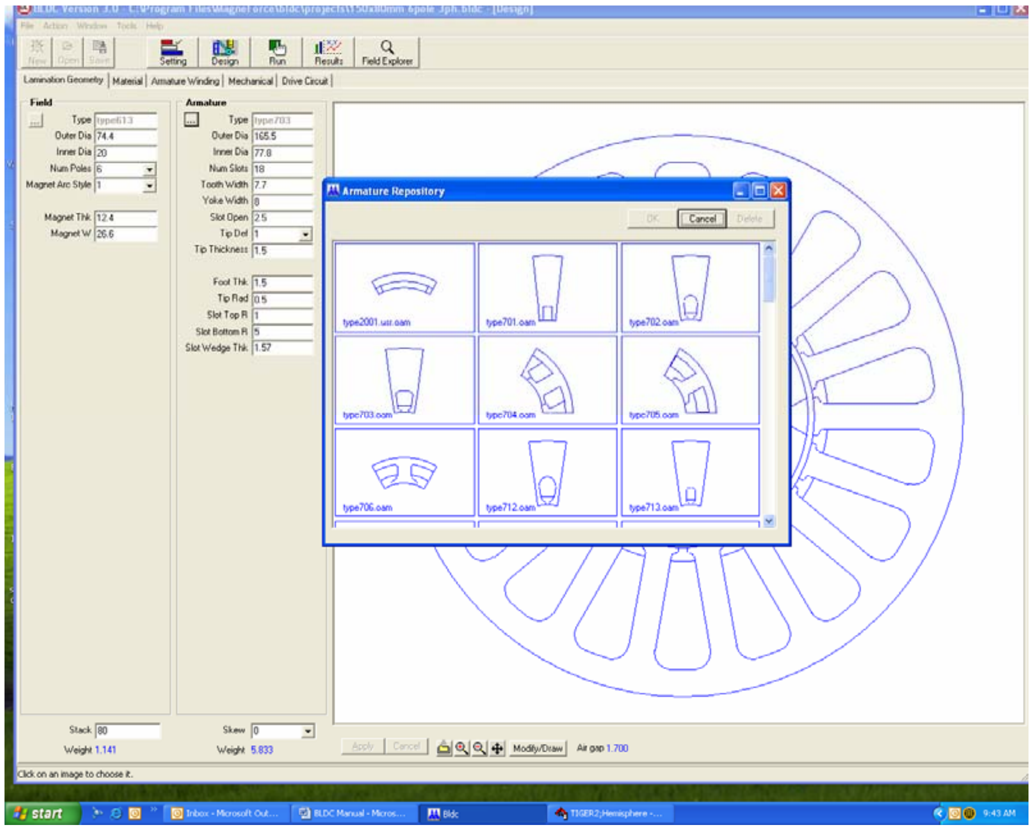
- The list button to the left of the **Type** field allows you to select the rotor geometry from a pop up window.
- **Outer Dia** is the rotor outside diameter including magnets measured in millimeters.
- **Inner Dia** is the diameter of the machine shaft measured in millimeters.
- **Num Poles** allows you to select the number of poles of the machine from the drop down list.
- **Magnet Arc Style** is set to 1 if the magnet arc is measured from the rotor center or 2 if the arc is measured from the tip of the magnet, if so enter arc value.
- **Magnet Thk** is the thickness of the permanent magnet material measured in millimeters.
- **Magnet Width** is the width of each magnet piece in millimeters.



The armature parameters will vary depending upon the exact geometry chosen. The following is for a type 703 armature:

- The list button to the left of the **Type** field allows you to select the armature geometry from a pop up window.
- **Outer Dia** is the armature outside diameter, measured in millimeters.
- **Inner Dia** is the armature inside diameter measured, in millimeters.
- **Num Slots** is the number of armature slots. This parameter must be an integer multiple of the number of phases.
- **Tooth Width** measured at the tooth stem in millimeters.
- **Yoke Width** is the distance from the bottom of the slot to the outside diameter of the armature, in millimeters.
- **Slot Open** is the slot width at the opening, measured in millimeters.
- **Tip Def**
- **Tip Thickness** at the slot opening in millimeters.
- **Foot Thk** foot back thickness in millimeters.
- **Tip Rad** tip radius in millimeters.
- **Slot Top R** corner radius at top of slot in millimeters.
- **Slot Bottom R** corner radius at bottom of slot in millimeters.

- **Slot Wedge Thk** is used if slot wedges are used and is the thickness from the inner diameter towards the outer diameter, measured in millimeters.



The general machine parameters near the bottom of the screen are:

- **Stack** is the length of machine measured in millimeters.
- **Skew** is the machine skew end to end measured in slots.
- **Weight** is a calculated value of the rotor and stator lamination's weight in kilograms.

The program will calculate the machine air gap based upon your input dimensions. If the resultant air gap is negative, it will be displayed in red.

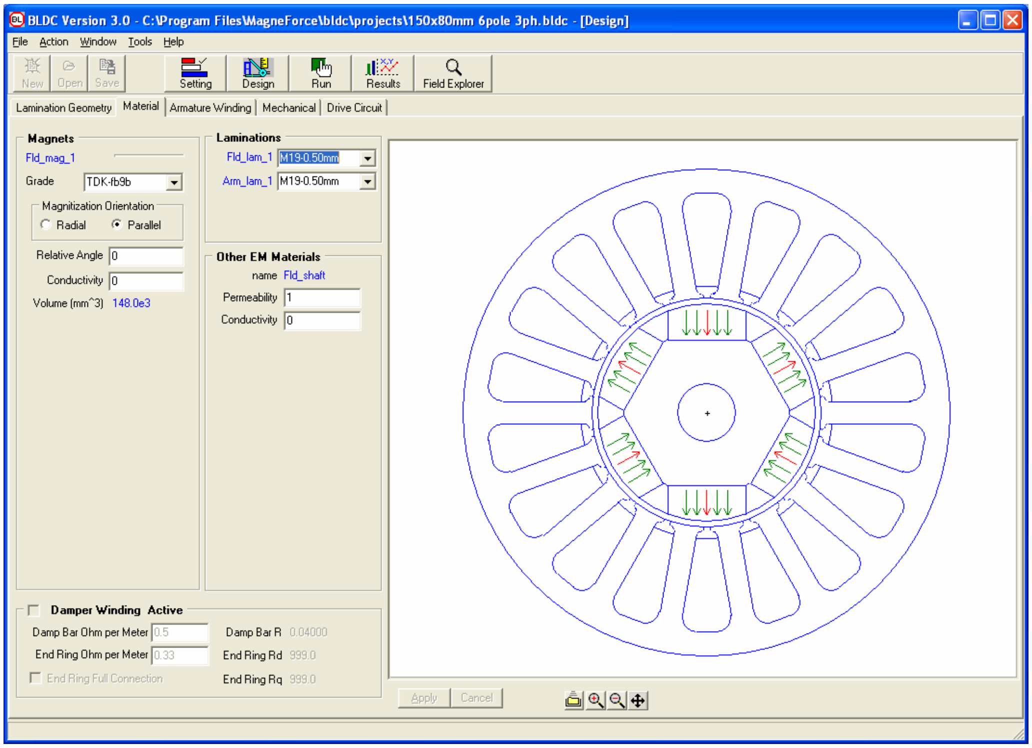
Please note that when making large wholesale changes to the machine dimensions, the graphical display may be left blank or seem distorted. This is due to the fact that some geometry parameters have changed while others have not yet been updated. Continue with your geometry change inputs and the display will return to normal once all parameters have been correctly updated.

Under the drawing of the machine cross section is an APPLY and CANCEL button. These buttons are used to apply or cancel changes in the geometry figures from above. Next to these are four buttons for FIT ALL, ZOOM IN, ZOOM OUT and MOVE. They can be used together with the scroll bars to enlarge and inspect your geometry. When satisfied, click the FIT ALL button to return the cross section to normal size.

The button MODIFY/DRAW button is used to launch ARBIDRAW which is MagneForce's stand alone drawing package that will allow you to make major geometry changes to a slot module. Please see the ArbiDraw user manual for further explanation.

After you are satisfied with your design, use the SAVE button on the panel toolbar to commit your changes to disk.

MATERIALS TAB



This tab has sections on the left that describe the attributes of the permanent magnet material, steel laminations and other electromagnetic materials as applicable to the design. On the right is a drawing of the cross section of the rotor and below is an area that describes the damper bar windings.

The permanent magnet parameters are:

- **Grade** is the type of magnet material that the field is made from, select from the drop down list. If your particular material is not listed you may add it using the settings panel described in the next section.
- **Magnetization Orientation** describes how the permanent magnets are magnetized. Choose radial if the magnetic field emanates radially from the rotor or parallel if the field lines are parallel to each other.
- **Center Offset** is active only when radial orientation is chosen. It is the angle at which the field differs from straight radial.
- **Relative Angle** is active only when parallel orientation is chosen. It is the angle that the field differs from straight parallel.
- **Magnet Vol** is a calculated value of the permanent magnet volume measured in cubic millimeters.

The Lamination parameters are:

- **Field Lam** is the type of steel the field stack is constructed from, please select from the drop down list.
- **Armature Lam** is the type of steel the armature stack is constructed from, please select from the drop down list.

Please note that if your particular steel does not appear in the list you will have a chance to add it utilizing the settings panel which will be explained in the next section.

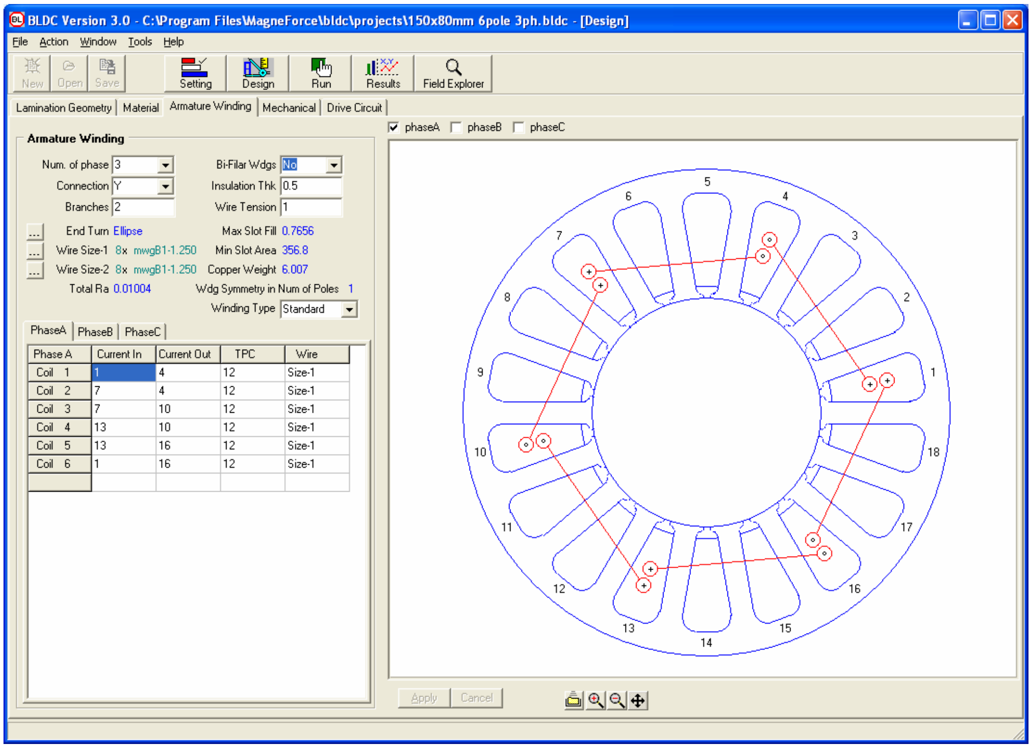
The damper bar parameters are:

- **Bar Ohm Per Meter** is the resistance of the bar material, measured in ohms per meter.
- **End Ring Ohm Per Meter** is the resistance of the end ring material, measured in ohms per meter.
- **Bar R** is a calculated parameter and is the actual machine bar resistance in ohms.
- **End Ring Rd** is a calculated parameter and is the d-axis resistance parameter of the end ring.
- **End Ring Rq** is a calculated parameter and is the q-axis resistance parameter of the end ring.
- **End Ring Full Connection** should be checked if all bars are connected to the end ring.
- **Damper Winding Active** should be checked if you would like the simulation to proceed with the effects o

Under the drawing of the machine cross section is an APPLY and CANCEL button. These buttons are used to apply or cancel changes in the geometry figures from above. Next to these are four buttons for FIT ALL, ZOOM IN, ZOOM OUT and MOVE. They can be used together with the scroll bars to enlarge and inspect your geometry. When satisfied, click the FIT ALL button to return the cross section to normal size.

After you are satisfied with your design, use the SAVE button on the panel toolbar to commit your changes to disk.

ARMATURE WINDING TAB



This tab describes the armature winding including wire size, numbers of turns, and connection type. The tab has sections on the left that describe the armature winding attributes. On the right, is a graphical representation of the cross section of the rotor.

- **No of Phases** is the number of phases of the armature windings.
- **Connection** can be either "Y" or Delta, choose from the drop down list.
- **Branches** is a parameter that describes how the coils are connected to each other to form the winding. If they are connected in series then branches are 1, if they are connected in parallel then branches are 2 or higher. Simply put branches is the number of parallel paths through a particular phase winding.
- **Bi-Filer Wdgs** can be set to either YES or NO, indicating whether or not the drive circuit uses a b-filer design in which there are no low side switches.
- **Insulation Thk** is the thickness of the insulating material that surrounds the interior of the slot in millimeters.

- **Wire Tension** is the tension with which the coil is wound, this tension can affect the resistance of the coil. A value of 1 indicates no deformation of the wire during winding.
- **Winding Type** can be either set to standard or fractional, select from the drop down list. A standard winding is one in which full winding symmetry exists in each pair of poles. A fractional winding is one in which full winding symmetry does not exist in each pair of poles but does exist within each phase.
- **Wire Size-1 & Wire Size-2** is the gauge of the wire used to wind the coils. Select these from the table by clicking the select button to the left of the name. Also included in this table is the **Parallel Strands** parameter. This parameter specifies the number of parallel strands that the winding is composed of. The reason there are two Wire Size parameters is so that a winding may be composed of two wires of different sizes. The actual existence of each size is specified in the winding table below.

Based upon your input, several parameters are calculated

- **Ra** is the phase resistance as viewed from the machine's terminals.
- **Min Slot Area** is cross sectional area of the slot measured in square millimeters.
- **Max Slot Fill** is the percentage fill of the fullest slot.
- **Copper Weight** is the weight in kg of the copper winding specified in the winding table.
- **Wdg Symmetry in Number of Poles** is the symmetry if any that exists in the winding as related to the number of poles. This parameter can help spot an unintentionally unbalanced winding and is used to determine how the machine is solved. For example a 60 degree phase belt winding can be solved in one pole while a 120 degree phase belt winding must be solved in two poles.

The table below these parameters, together with the drawing to the right, describe exactly how the coils are wound within the slots of the armature. The table lists the coils (which are calculated based upon your input on the lamination geometry tab) from beginning to end. To describe the winding, fill in the columns CURRENT IN, CURRENT OUT, TPC and WIRE for all coils.

- **CURRENT IN** is the slot number, for this coil, in which current would travel into the computer screen.
- **CURRENT OUT** is the slot number, for this coil, in which current would travel out from the computer screen.

- **TPC** is the number of turns per coil. This is the physical number of wires that belong to this coil, however be careful not to confuse this with the number of strands. For instance a coil that is wound with 5 strands in hand but only 2 turns per coil would have a TPC setting of 2 and not 10.
- **WIRE** can be set to SIZE 1, SIZE 2 or SIZE 1&2. Simply place the cursor in the WIRE column on each line and click to toggle to the correct setting. The actual size of the wire is specified above in the WIRE SIZE tables.

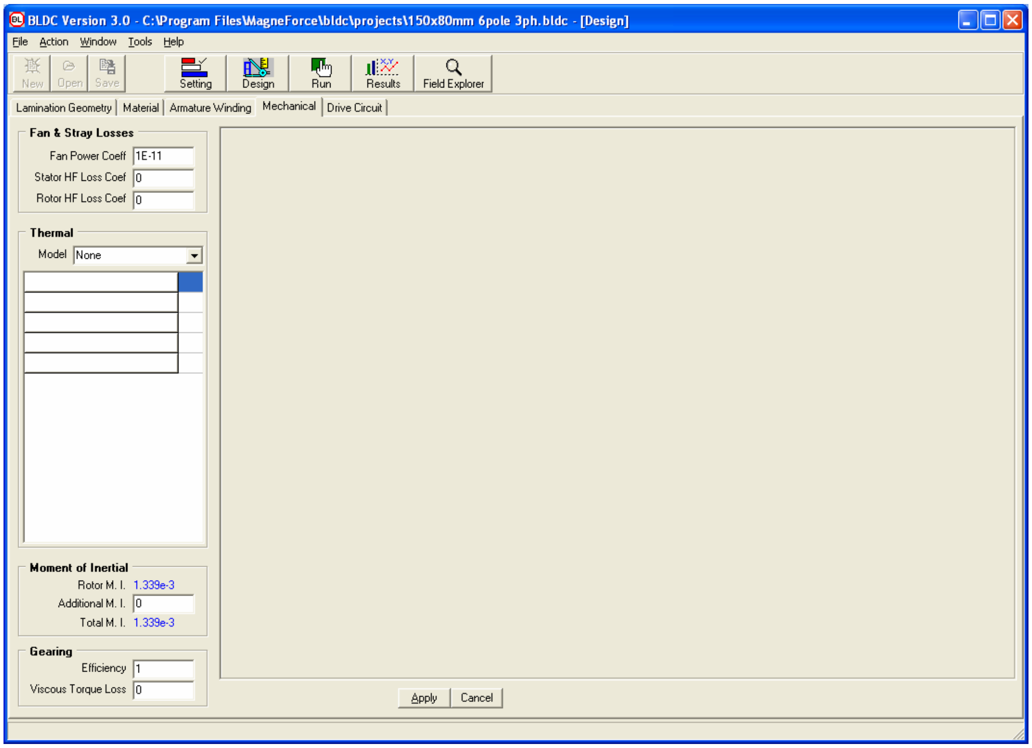
Along the right hand side of the table are three tabs labeled PHASE A, PHASE B and PHASE C. In the case of a standard winding the program will complete the winding tables for PHASES B and C based upon your input from PHASE A. In the case of a fractional winding you must click each tab and complete the winding table for each phase individually.

Just above the armature drawing are three check boxes for the three phases of the machine. Checking each box will cause the corresponding phases' winding to be drawn. In this way one can often spot mistakes in the winding table, by comparing winding symmetry among the phases.

Under the drawing of the machine cross section is an APPLY and CANCEL button. These buttons are used to apply or cancel changes in the geometry figures from above. Next to these are four buttons for FIT ALL, ZOOM IN, ZOOM OUT and MOVE. They can be used together with the scroll bars to enlarge and inspect your geometry. When satisfied, click the FIT ALL button to return the cross section to normal size.

After you are satisfied with your design, use the SAVE button on the panel toolbar to commit your changes to disk.

MECHANICAL TAB

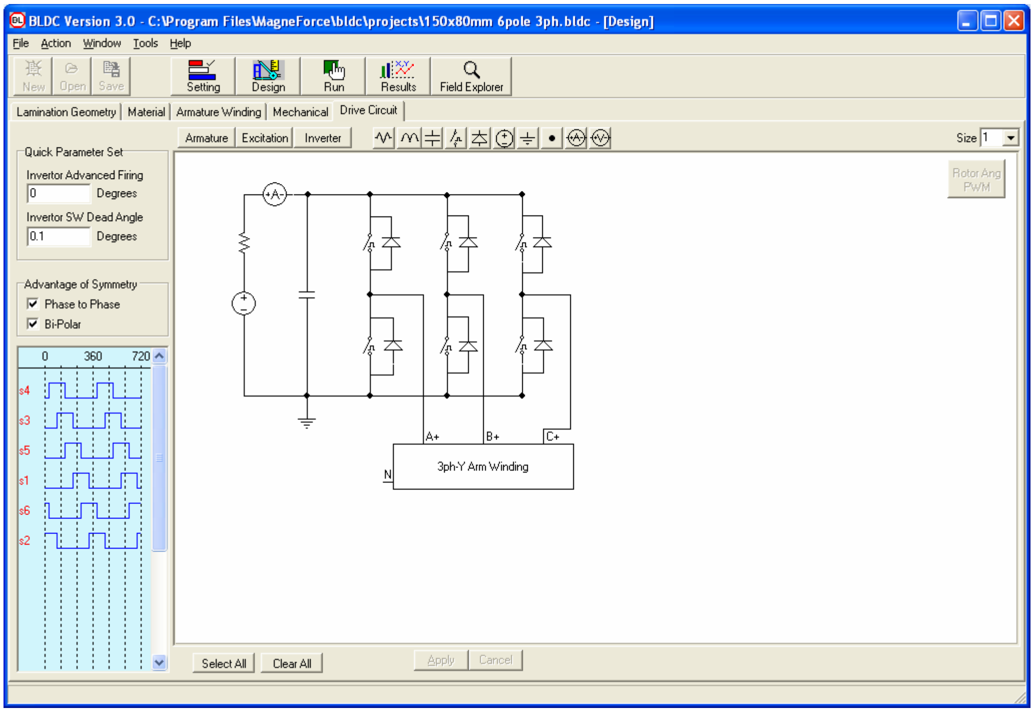


This tab allows you to enter mechanical parameters that describe the machine's mechanical properties. The active parameters are:

- **Fan Power Coeff** is a parameter that describes the wattage absorbed by the machine's fan in Watts per cubic rpm.
- **Stator HF Loss Coef** estimated high frequency eddy current loss in stator, in Watts per cubic rpm
- **Rotor HF Loss Coef** estimated high frequency eddy current loss in rotor, in Watts per cubic rpm
- **Thermal Model** drop down box to select external user defined thermal model (not yet implemented)
- **Rotor M. I.** is the calculated rotational moment of inertia of the rotor.
- **Additional M. I.** is any additional moment of inertia that you would like to add such as a fan or the load.
- **Total M. I.** is the sum of the above rotational and additional moments of inertia.
- **Gearing Efficiency** is the efficiency of any gearing attached to the motor in per unit.
- **Viscous Torque Loss** is any mechanical torque loss in the above gearing.

In the lower right corner is an APPLY and CANCEL button. These buttons are used to apply or cancel changes in the mechanical parameters from above. After you are satisfied with your design, use the SAVE button on the panel toolbar to commit your changes to disk.

DRIVE CIRCUIT TAB



Within this tab you will describe the schematic layout of the machine's drive circuit. The tab is divided into two major sections, the schematic drawing area to the right and a column to the left used for parameter settings and switch visualization. The operation of the drawing section is similar to many popular schematic drawing and capture packages. Using the drawing aids and component buttons along the top of the schematic area you can, quickly & easily, construct Brushless DC drive circuits ranging from simple rotor position feedback to complex PWM control. The drive circuit topology will then be used in the simulation of the machine.

The upper portion of the left hand column contains several parameter settings.

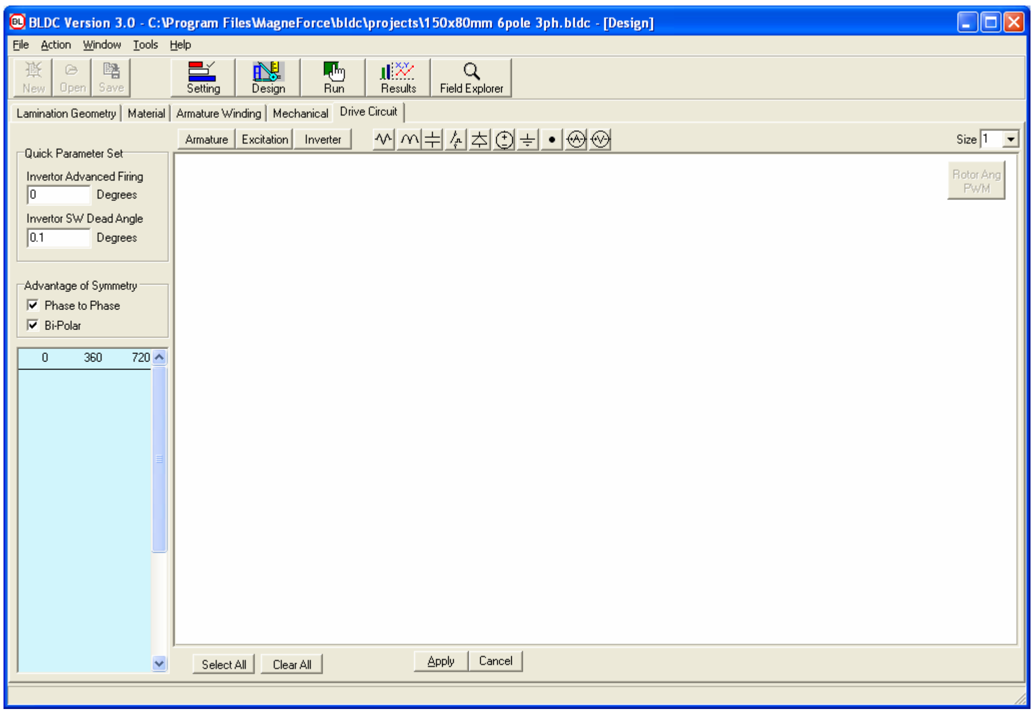
- **Inverter Advanced Firing** is the amount, in degrees, that you wish to advance fire the inverter switches.
- **Inverter Switch Dead Angle** is the amount, in degrees, that you wish to reserve between one inverter switch turning off and the next switch turning on.

The middle portion of this column contains several symmetry settings. These settings are used to conserve simulation time. The program will use these

settings in determining exactly how much of the machine and how much of the complete AC cycle it needs to simulate.

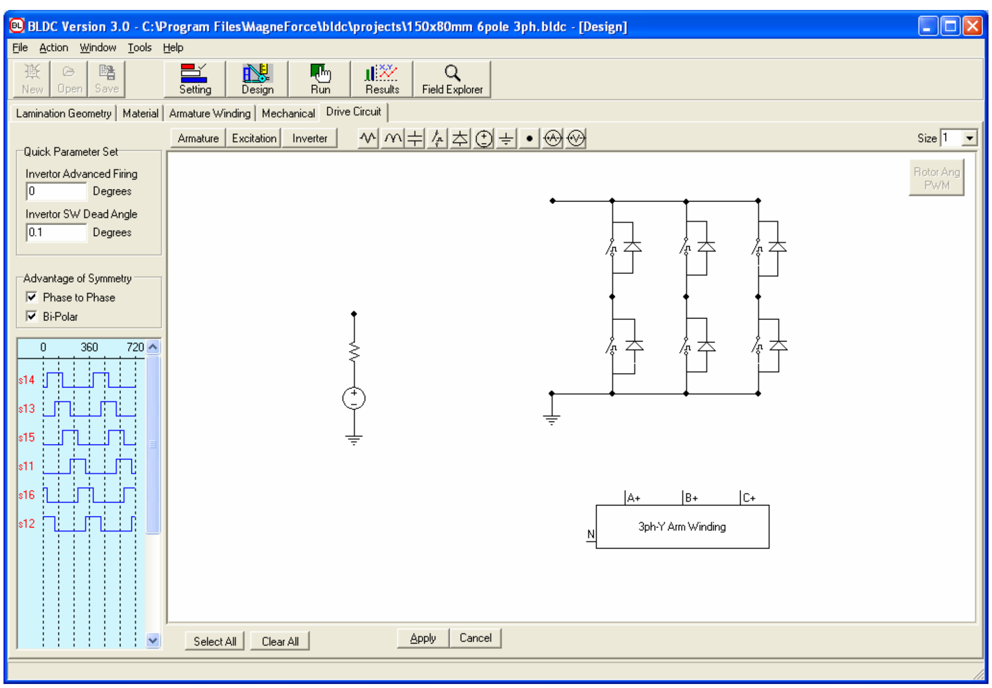
- **Phase to Phase** can be checked if the machine exhibits drive phase to phase symmetry.
- **Bi-Polar** can be checked if the drive circuit exhibits Bi-Polar symmetry.

The lower portion of this column is a graphical representation of the switch on-off sequence versus electrical degrees. In simple rotor position feedback control this area can provide a quick visual confirmation that you have set all of the switch on-off attributes correctly.



Beginning with a blank screen you may select any of the buttons above the schematic drawing area. Select the button you wish by rolling your mouse cursor over the item and clicking the left mouse button. Next move the mouse cursor into the schematic drawing area and place by clicking the left mouse button again. The selected item will now appear on the schematic drawing area. Depending upon the item selected access the item's attributes by right-clicking the item on the drawing area and selecting attributes. Each item has attributes that are appropriate to itself. Additionally, right clicking an item will allow you to rotate, flip, delete, copy and or paste the item. These options are available to the appropriate items.

- **Armature** will place an armature of the type that was selected on the armature winding tab previously. For example if a 3-phase Y connected winding was selected on the armature tab you will see a schematic of this exact armature with access to the following leads A, B, C and N. There are no attributes available for the armature item.
- **Excitation** will place one of three voltage sources onto the schematic drawing area. When initially selecting excitation you will be presented with 3 additional choices, V source, AC Bridge and DC Excitation. Choosing V source will place a simple ideal voltage source while choosing AC Bridge will place a standard AC bridge rectifier voltage source and choosing DC Excitation will place a standard voltage source in series with a resistor, onto the drawing area. The attributes of the actual voltage source in each of these excitation models can be accessed by right clicking the source itself. Attribute options are AC or DC, voltage magnitude and frequency if AC is selected. Additionally, you can rotate or scale the objects size from this pop-up window as well. The other items such as resistors and diodes contained in the AC Bridge and DC Excitation models also have attributes that may be displayed by right clicking the actual device.
- **Inverter** will place onto the drawing area a standard drive circuit inverter based upon the exact armature selected on the armature tab previously. This inverter will be composed of the appropriate number of switches and diodes connected in a manner suitable to drive the selected armature. Each individual component in this preconfigured inverter is selectable and its attributes modifiable by right clicking the component itself.



Once the above three major components are placed onto the schematic drawing surface any additional components such as filter capacitors or inductors, shut resistors, extra switches or diodes may be placed onto the drawing surface. Each individual component will have a specific set of attributes, detailed below, available for setting and accessed by right clicking the component itself. Each component's attribute box will allow the component to be scaled in size or rotated on the page.

- **Resistor** attributes include name and resistance. The resistor name is automatically generated sequentially, however it may be changed if desired and the resistance value is set in Ohms.
- **Inductor** attributes include name and inductance. The inductor name is automatically generated sequentially, however it may be changed if desired and the inductance value is set in Henrys.
- **Capacitor** attributes include name and capacitance. The capacitor name is automatically generated sequentially, however it may be changed if desired and the capacitance value is set in Farads.
- **Switch** attributes include name, control, and a junction resistance model.

    Name the switch name is automatically generated sequentially, however it may be changed if desired.

    Control

    Rotor Ang

    Phase Ang in simple rotor position feedback control, the degree at which the switch will turn on.

    Algorithm can be set to one of 4 different choices, which determines simple rotor position feedback (local square voltage) or one of 3 different PWM control schemes which are described in more detail in the next section.

    On Band Width amount of time the switch will remain on, in degrees

    Time the switch operates for a predetermined time as described by the following parameters.

    Delay the delay, in seconds, if any, before the switch starts operating.

    Algorithm Pulse-Local used to pulse the switch according to the following parameters or **Time Local** used to control the switch according to time.

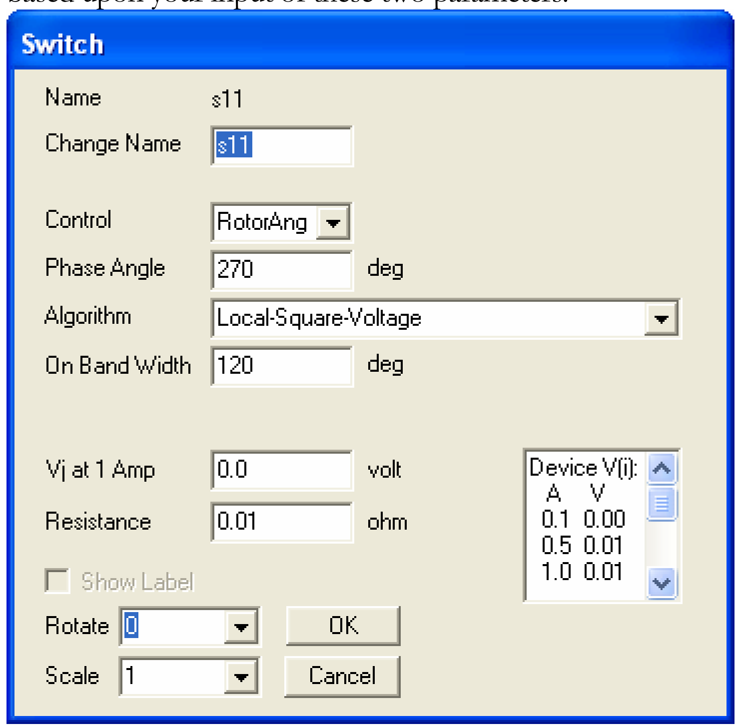
    Frequency the frequency of the pulse

    Duty Cycle in per unit, the ratio of the on to off time of the switch

Duration is the time the switch remains closed in seconds.
Cycle is the time in seconds that the whole operation will repeat. Be careful with this parameter it should always be greater than the duration parameter above.

Vj at 1 amp is the switch junction voltage drop at 1 amp. See below.
Resistance is the switch junction resistance. See below.

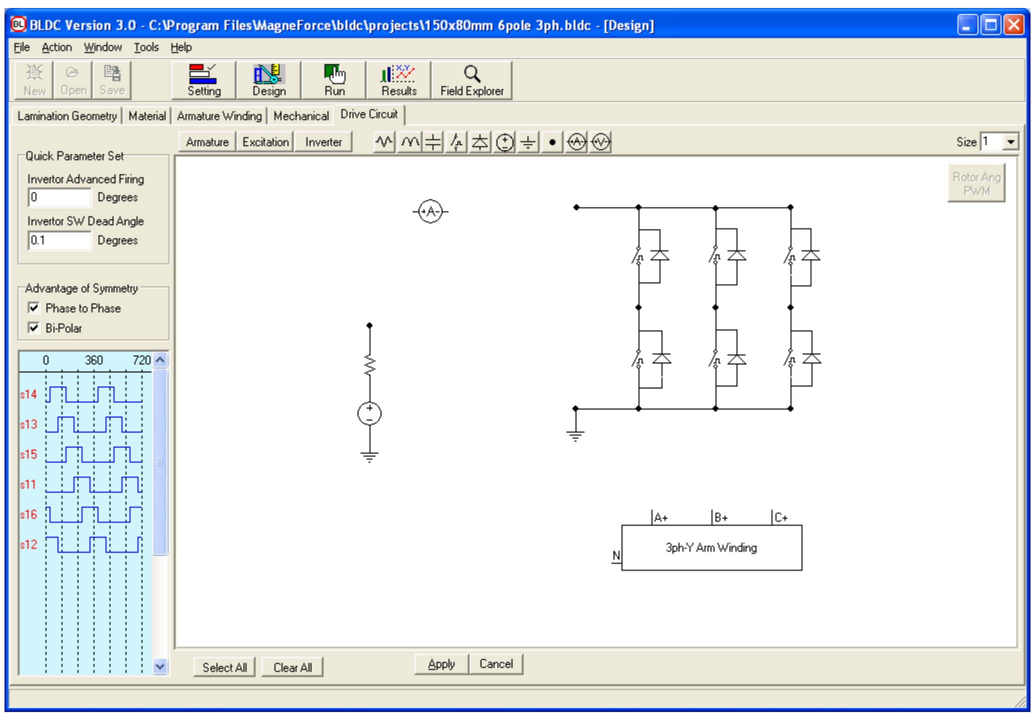
These parameters should be available from the data sheet of the device and are used to construct a switch resistance model based upon the current flow through the device. The window to the right of these parameters shows the current vs voltage relationship of this switch based upon your input of these two parameters.



- **Diode** attributes consist only of name which is automatically generated sequentially, however may be changed if desired.
- **Voltage Source** attributes consist of name, source type AC or DC, magnitude
- **Ground point** must be set as a reference, typically on the negative lead of the excitation source. The ground point does not have any attributes.
- **Intersection point** is used to connect multiple component leads to a common voltage point within the circuit. It's attributes consist only of

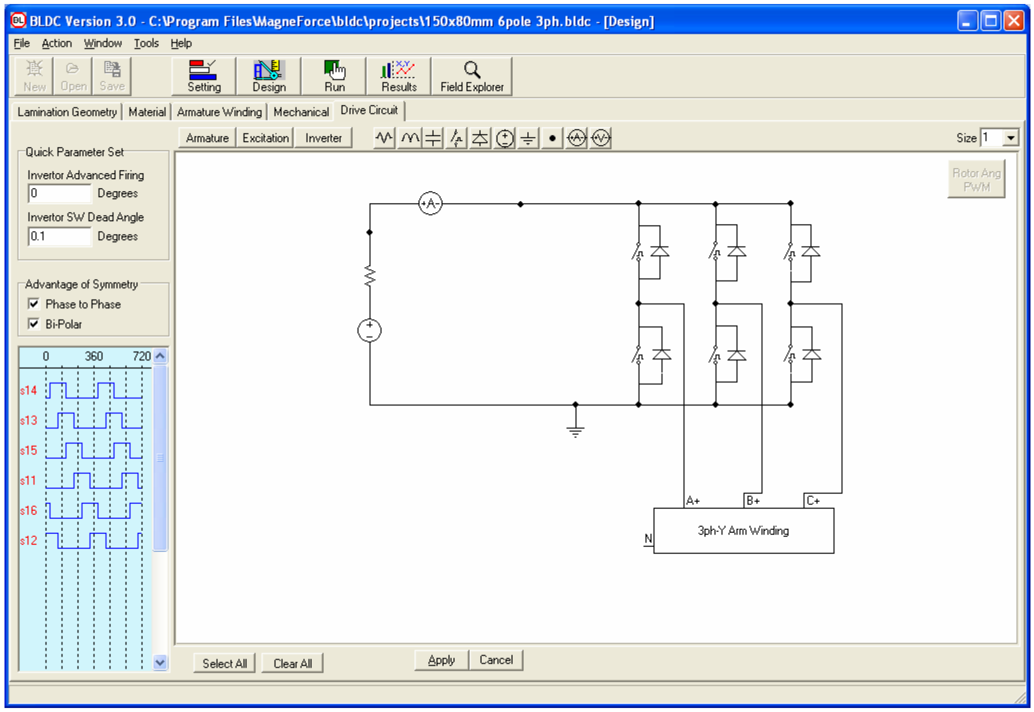
name which is automatically generated sequentially, however may be changed if desired.

- **Ammeter** can be placed anywhere within the circuit in which you would like to know the current. Upon simulation the results of this meter will appear in the results portion of the program. It's attributes consist only of name which is automatically generated sequentially, however may be changed if desired.
- **Voltmeter** can be placed across any portion of the circuit in which you would like to know the voltage. Upon simulation the results of this meter will appear in the results portion of the program. It's attributes consist only of name which is automatically generated sequentially, however may be changed if desired.



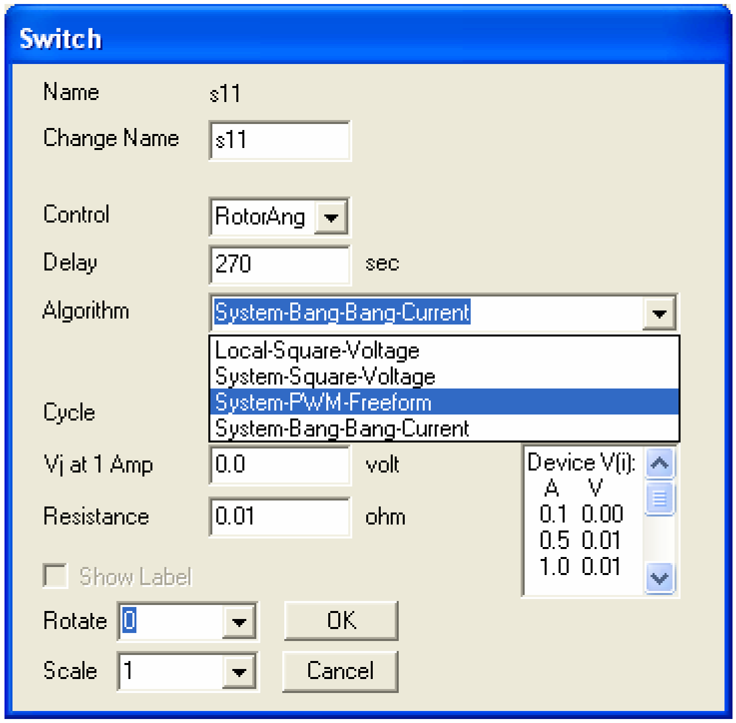
Once all appropriate components have been placed upon the schematic drawing area you may connect them to form the desired drive circuit. To connect components roll your cursor over the device endpoint until a red circle appears. At this point left click and drag to the next component. Please note that as soon as you left click the first component the cursor will change to

a hand symbol and remain until the connection to the other component is made. You may move individual components or connection lines by simply clicking and dragging the component to its desired location.



When all suitable connections and movements have been made select Apply at the bottom of the drawing area and your circuit will be saved. At any time before you click Apply you can click Cancel and all changes in the drawing area since the last Apply will be erased. To the left of the Apply and Cancel buttons are the Select all and Clear All buttons. Use the Select All button to highlight all components on the drawing area. You may then click and drag all the components as a group. The Clear All button will clear the entire drawing area.

In the upper right hand corner of the drawing area there is a button labeled **ROTOR ANG PWM**. This button allows access to the 3 different PWM control schemes that are part of BLDC. The button is normally graded out until a PWM control scheme is selected in the attributes of at least one of the inverter switches. It is important to note that all switches should be set similarly, it would not make any sense to have some of the switches operating under one control scheme while others are following a different scheme. To set each switch, double click it and select one of the **SYSTEM** modes in the **ALGORITHM** parameter as shown below.


Switch
Name
s11
Change Name
s11
Control
RotorAng
Delay
270
sec
Algorithm
System-Bang-Bang-Current
Local-Square-Voltage
System-Square-Voltage
System-PWM-Freeform
System-Bang-Bang-Current
Cycle
Vj at 1 Amp
0.0
volt
Resistance
0.01
ohm
Device V(i):
A V
0.1 0.00
0.5 0.01
1.0 0.01
Show Label
Rotate
0
OK
Scale
1
Cancel

Once all system switches have been set appropriately you may click on the **ROTOR ANG PWM** button to further define the selected control scheme. The 3 different PWM modes that BLDC can simulate are as follows:

System Square Voltage uses a strategy to try and keep the phase voltage to the motor to be a square wave.

Conduction Band is the conduction band in degrees of the base waveform

PWM Style Frequency is either set to FIXED or Fc/Fb and is the style of the frequency of the carrier wave.

PWM Freq or Carrier/Base if above parameter is set to FIXED then this is the frequency of the carrier wave, if above is set to Fc/Fb then this specifies the ratio of the carrier to base frequency.

Modulation Index is an index that controls the PWM switching

Feedback Control specifies whether feedback is employed and can be set to NONE, TARGET-CONTROL or LIMIT-CONTROL.

None no feedback is utilized

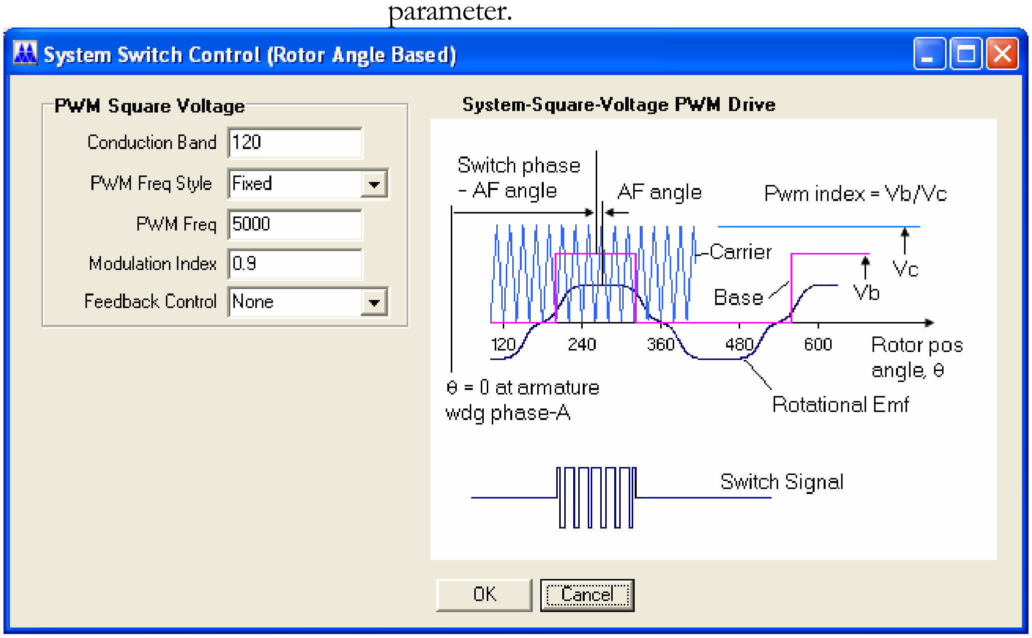
Target Control is a targeted or desired value that you wish to achieve

Limit Control is an upper limit value that you do not wish to exceed.

Target describes the targeted parameter either the armature phase current (Armature A) or the DC Bus current (I am11)

Measurement describes the measurement of the above parameter either RMS, Average or Instantaneous.

Value the actual targeted value of the above parameter.



System PWM Freeform employs a control strategy to try and keep the phase voltage to the motor to be a sine wave.

Base Waveform is either set to SINE or FOURIER. If Fourier is chosen then the table below should be filled in with the magnitude and phase of the Fourier series you would like to use to create the Base waveform.

PWM Style Frequency is either set to FIXED or Fc/Fb and is the style of the frequency of the carrier wave.

PWM Freq or Carrier/Base if above parameter is set to FIXED then this is the frequency of the carrier wave, if above is set to Fc/Fb then this specifies the ratio of the carrier to base frequency.

Modulation Index is an index that controls the PWM switching

Feedback Control specifies whether feedback is employed and can be set to NONE, TARGET-CONTROL or LIMIT-CONTROL.

None no feedback is utilized

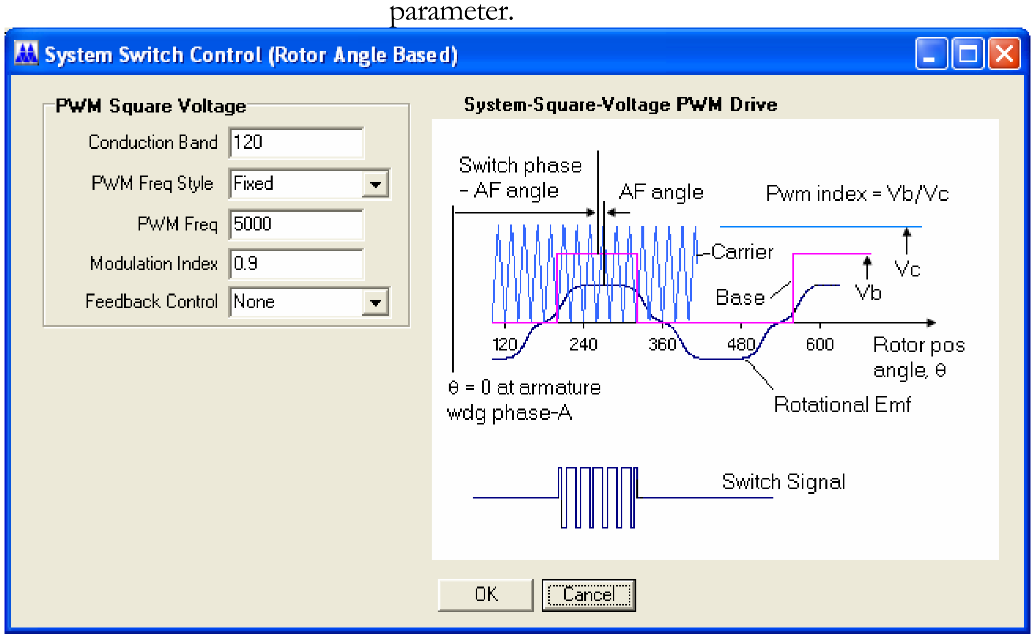
Target Control is a targeted or desired value that you wish to achieve

Limit Control is an upper limit value that you do not wish to exceed.

Target describes the targeted parameter either the armature phase current (Armature A) or the DC Bus current (I am11)

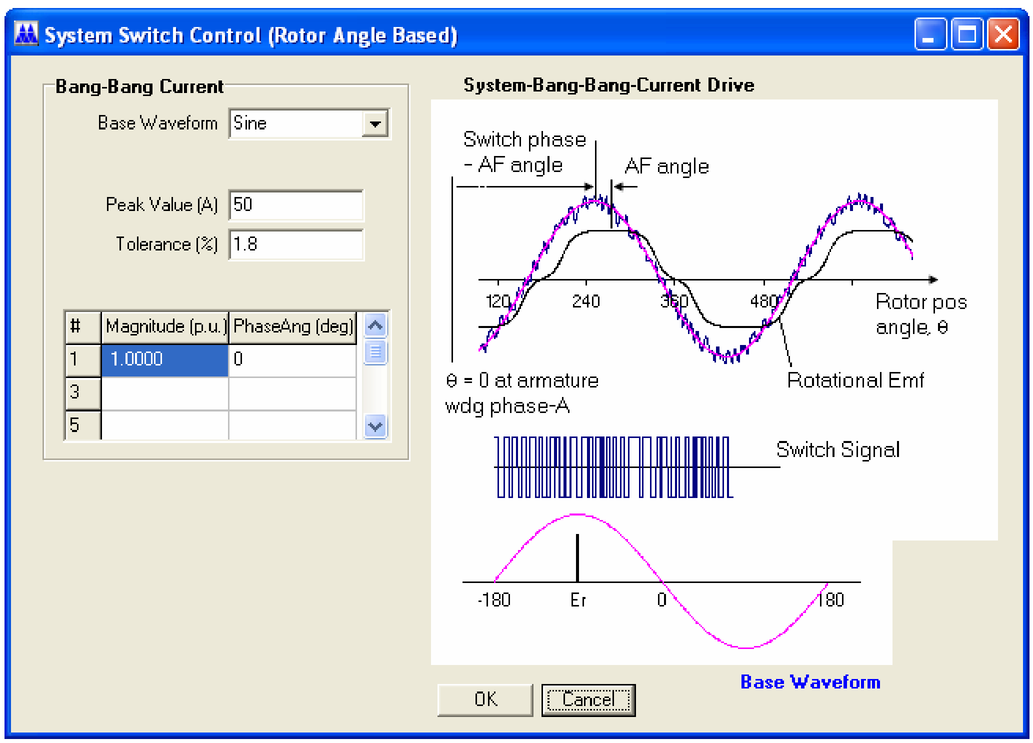
Measurement describes the measurement of the above parameter either RMS, Average or Instantaneous.

Value the actual targeted value of the above parameter.



System Bang-Bang Current employs a control strategy to try and keep the motor phase current as close to a specified waveform (sine, trapezoidal or square) as possible.

Base Waveform is either set to SINE, TRAPEZOID, SQUARE or FOURIER. If Fourier is chosen then the table below should be filled in with the magnitude and phase of the Fourier series you would like to use to create the Base waveform.
Conduction Band active only for the Trapezoid or Square wave options and is the width of the base wave
Peak Value is the maximum of the phase current that we are trying to control.
Tolerance is the tolerance around the above peak value that the control scheme will operate around.



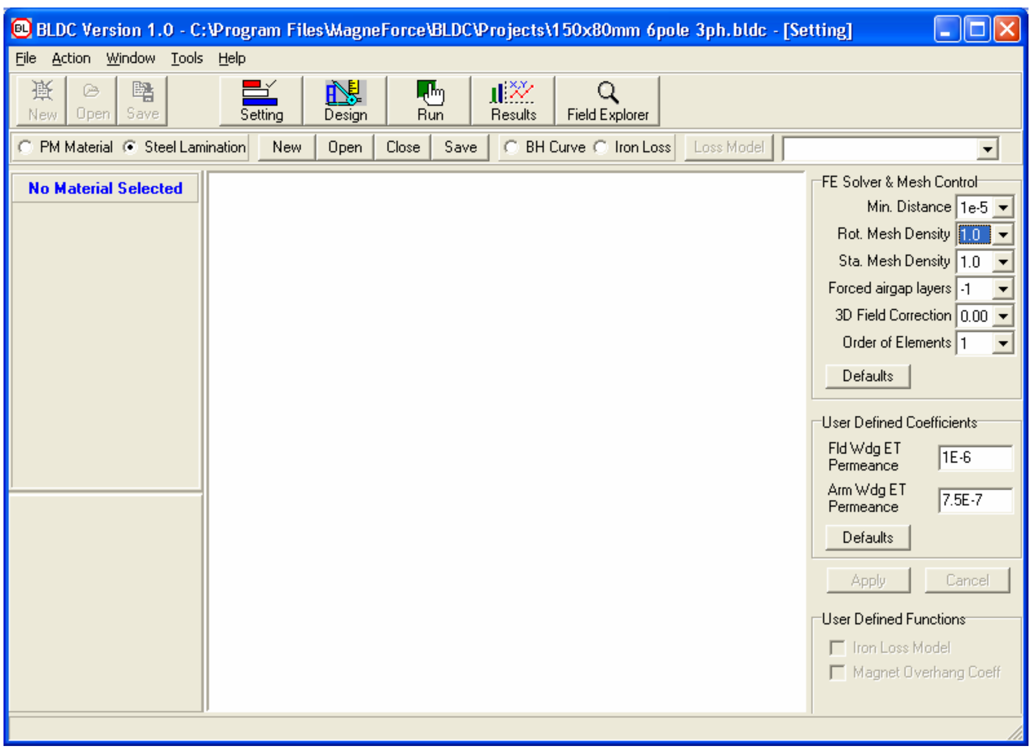
Chapter

6

The Settings Panel

This panel allows you to examine and adjust the material properties of all magnetic materials loaded into the MagneForce suite of simulators. Here you will find magnetic curves for both steel and permanent magnet materials. This panel also contains global software parameters that control such things as mesh density.

When first selected the settings panel will be displayed as:



FINITE ELEMENT SOLVER & MESH CONTROL PARAMETERS

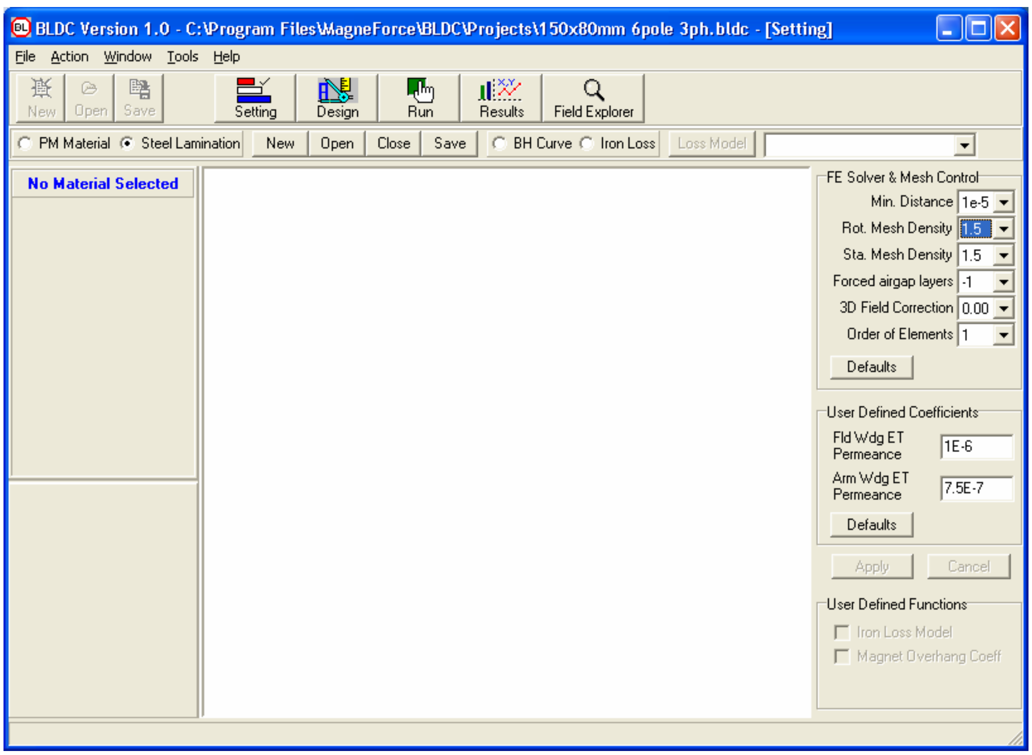
On the right side of this panel are several parameters that apply globally to the solver and to the generation of the finite element mesh. The default button can be used to restore these parameters to their original values.

- **Min Distance** is the minimum distance that will be allowed between two nodes. This value should not normally need to be adjusted.
- **Rot. Mesh Density** is a factor that controls the density of the rotor mesh. A value of 1 indicates a "normal" mesh density. Decreasing this parameter will cause the mesh density to decrease, while increasing it will cause the mesh density to increase.
- **Sta. Mesh Density** is a factor that controls the density of the stator mesh. A value of 1 indicates a "normal" mesh density. Decreasing this parameter will cause the mesh density to decrease, while increasing it will cause the mesh density to increase.
- **Forced Air Gap Layers** determines the number of node layers that will be forced within the airgap. A value of -1 indicates that no forcing of layers will be done. This setting allows the program to determine the number of air gap layers. Values of 0, 1 or 2 indicate this specific number of layers of nodes will be forced.
- **3D Field Correction** is parameter that corrects for 3D effects. If your machine is heavily saturated you can choose to add up to 10% flux linkage & inductance due to the end effects with this parameter.
- **Order of Elements** can be set to either 1 or 2 to use first or second order finite elements. Please note that cogging torque calculations always use second order elements.

USER DEFINED COEFFICIENTS & FUNCTIONS

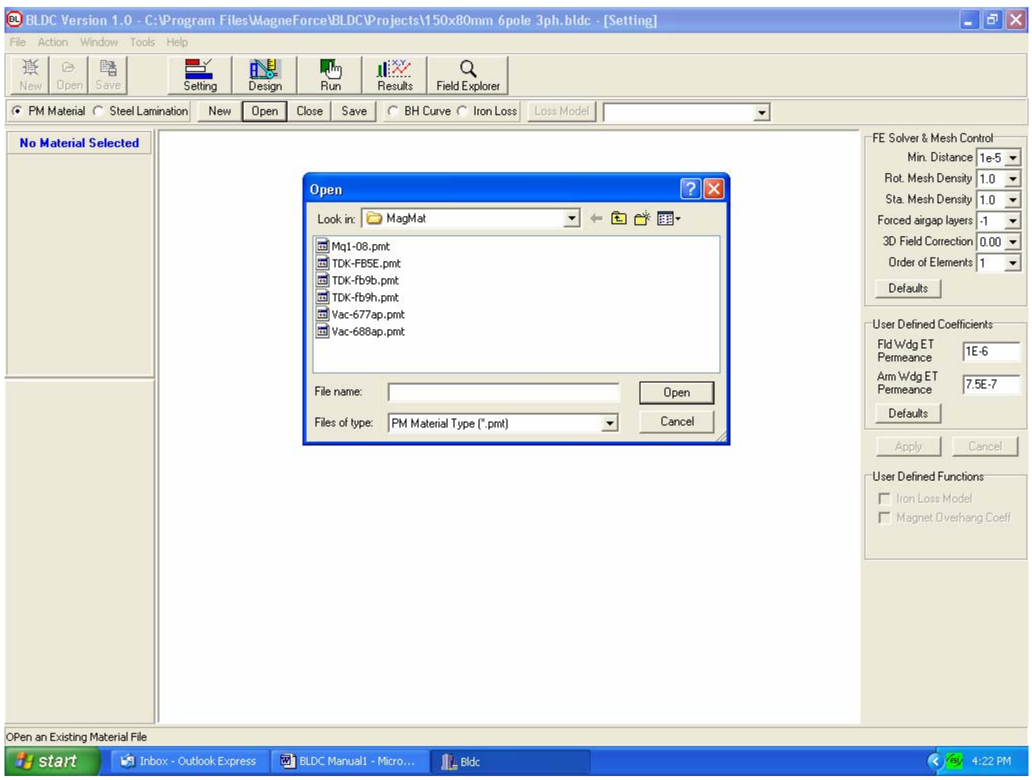
Under the solver and mesh control parameters are several settings that allow the user to describe end-turn effects and to invoke an iron loss model and/or a permanent magnet overhang model. The default button can be used to restore these parameters to their original values.

- **Fld Wdg ET Permeance** is a coefficient that describes the permeance of the end-turn winding of the field.
- **Arm Wdg ET Permeance** is a coefficient that describes the permeance of the end-turn winding of the armature.
- **Iron Loss Model** is currently not implemented within BLDC.
- **Magnet Overhang Coeff** is currently not implemented within BLDC.

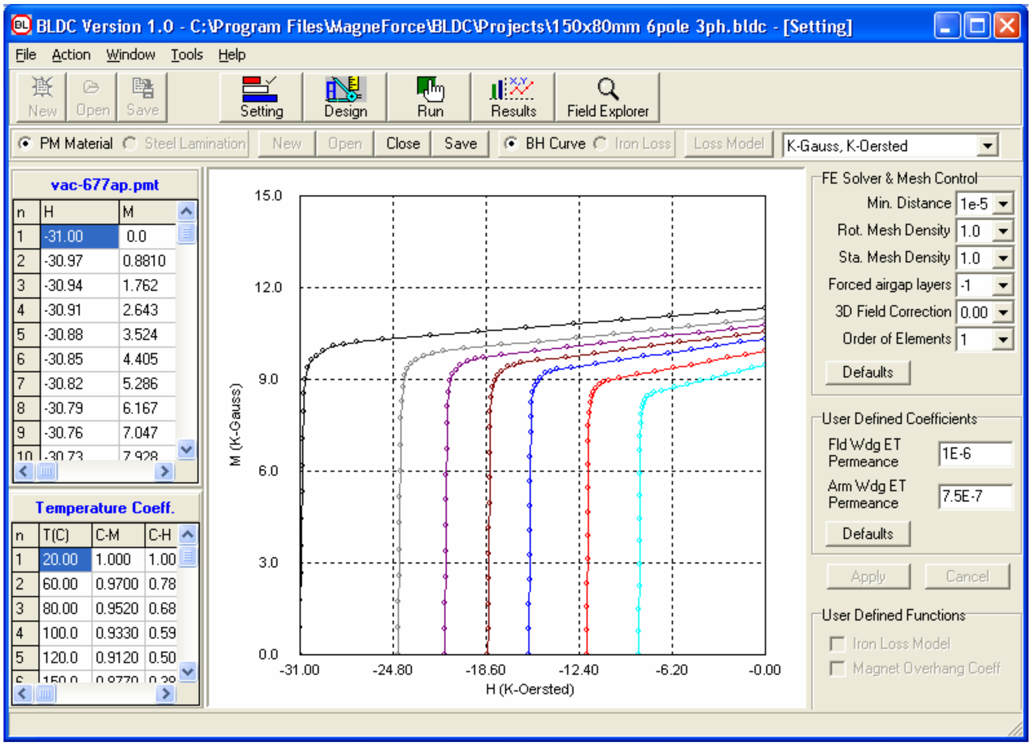


PERMANENT MAGNET MATERIAL DEFINITION

On the magnet tab of the design panel, you were required to select a permanent magnet material for the rotor. This section explains how to view and modify an existing material's properties or define a new material. Towards the upper left corner of the settings panel is a box that allows you to select either PM MATERIAL or STEEL LAMINATION. Select PM MATERIAL and then click OPEN to the right. This will bring up a list of all permanent magnet materials saved within the MagneForce suite of simulators.



Select a material from the list and click OPEN.

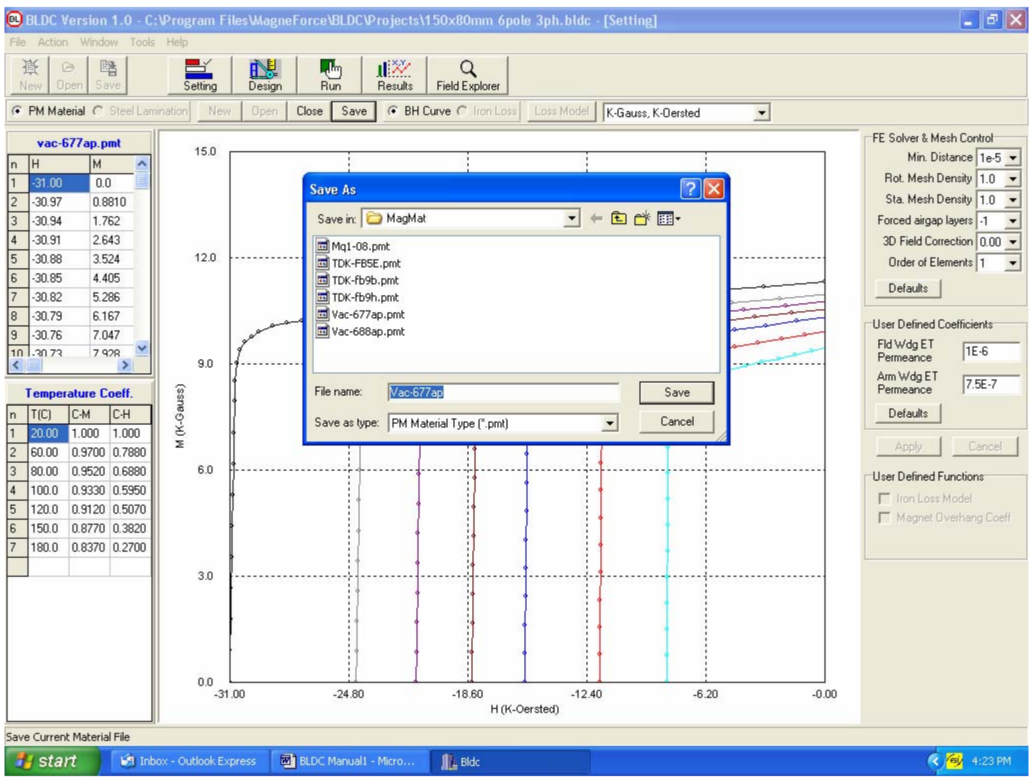


This screen displays in tabular and graphical form several B-H curves for the selected permanent magnet material. Each curve is at a different temperature. The name of the selected material appears above the upper table which is the B-H curve at 20 degrees Celsius. The lower table is the temperature coefficient table which describes how the B-H curve changes with increasing temperature. The columns in this table (C-M and C-H) are temperature coefficients that are simply multiplied by the B-H values at 20 degrees Celsius. Doing so yields the successive curves in the graph at the right. You will notice that the number of curves in the graph equals the number of tabular entries in the temperature coefficient table. Additionally, as you highlight an entry in this table, the corresponding curve is accentuated.

The values in the two tables can be adjusted and the results reflected in the curves to the right. Simply click on an entry and change it. The table will be immediately sorted and the graph updated. Additional data points can be added by using the scroll bars to position the cursor at the end of the table. Simply enter your new values and the graph and table will again be immediately updated.

The viewable size of the two tables and the graph area can be changed. Simply position your cursor on the area between either the tables or between a table and the graph area and click and drag to the desired size.

After modifying the material properties, you may click the SAVE button along the top of the settings panel. Upon doing so, the program will open a dialog box requesting you to save the material with a new name. The system will not allow you to over-write a default material. If however you have opened a user defined material the system confirms that you wish to over-write the existing material and does so.

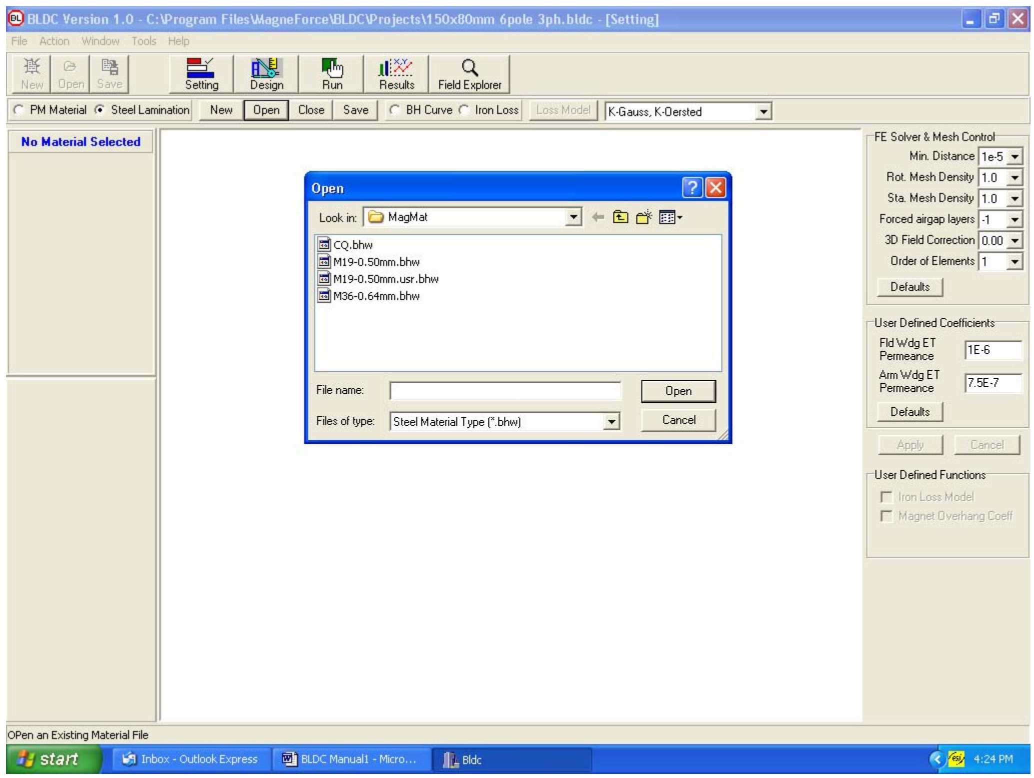


A new material can be defined by closing any open material, using the CLOSE button and then clicking the NEW button. The system will request a name and then open the material with blank tables. You can then populate the tables with data points and when finished save the new material. This new material will now be available to all MagneForce Simulators.

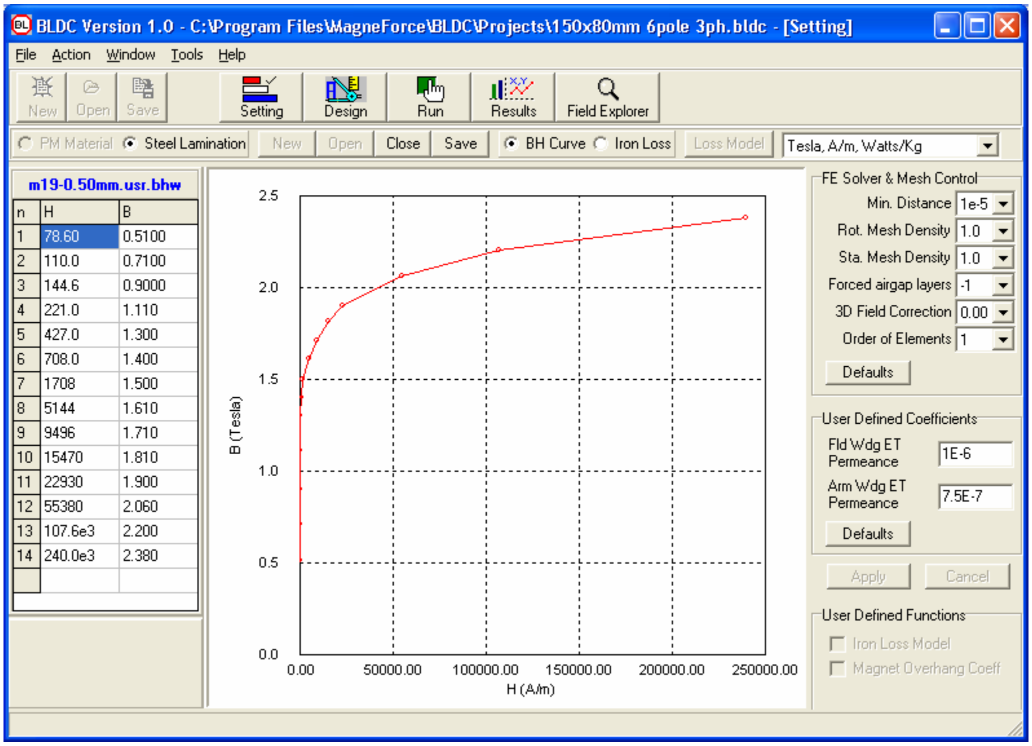
In the upper right corner of the settings panel is the units selector drop down box. This selector box allows you to view the B-H curves and tables in the units of your choice. The available selections are Tesla & A/m or Gauss & Oersted or KGauss & KOersted. Select the units you are most comfortable with.

STEEL LAMINATION MATERIAL DEFINITION

Similar to the permanent magnet material, BLDC provides for the characterization of different steel materials. On the settings panel in the upper left corner, click STEEL LAMINATION, then to the right click OPEN. A dialog box will appear requesting you to select a steel material from a list of all materials saved within the MagneForce suite of simulators.



Select a material and click OPEN.

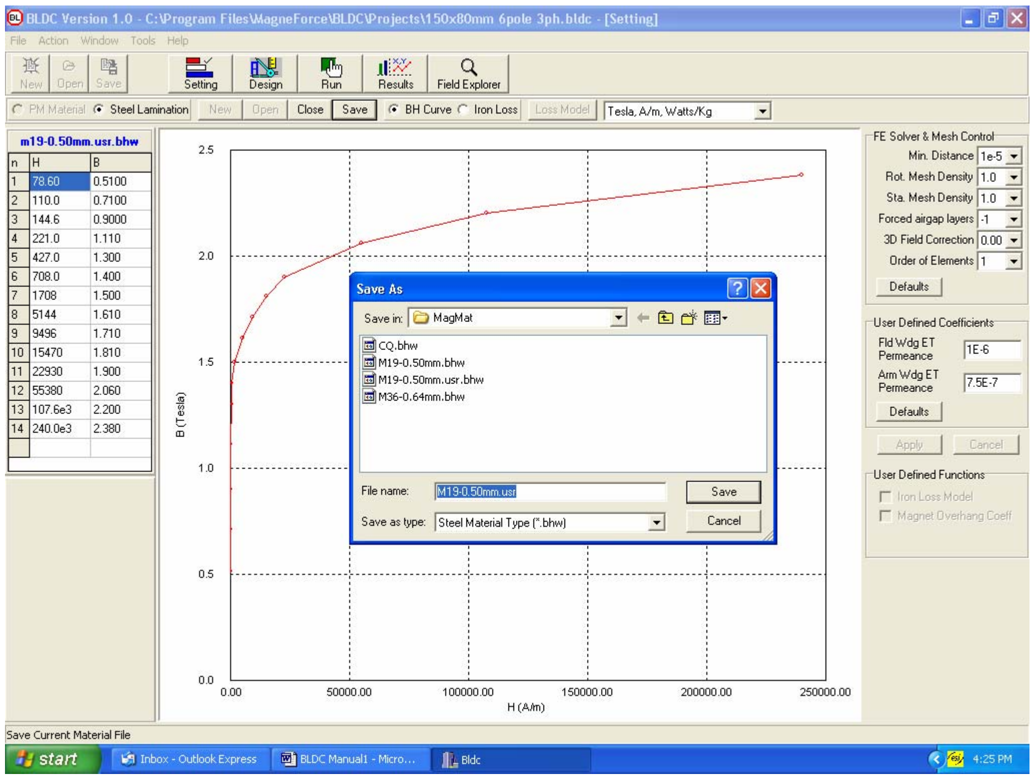


Similar to the permanent magnet material, the B-H curve for the steel material is displayed in both tabular and graphical format. The name of the selected material appears just above the B-H tabular values, while a graph of these points appears to the right.

The values in the table can be adjusted and the results reflected in the curve to the right. Simply click on an entry and change it. The table will be immediately sorted and the graph updated. Additional data points can be added by using the scroll bars to position the cursor at the end of the table. Simply enter your new values and the graph and table will again be immediately updated.

The viewable size of the table and the graph area can be changed. Simply position your cursor on the area between the table and the graph area and click and drag to the desired size.

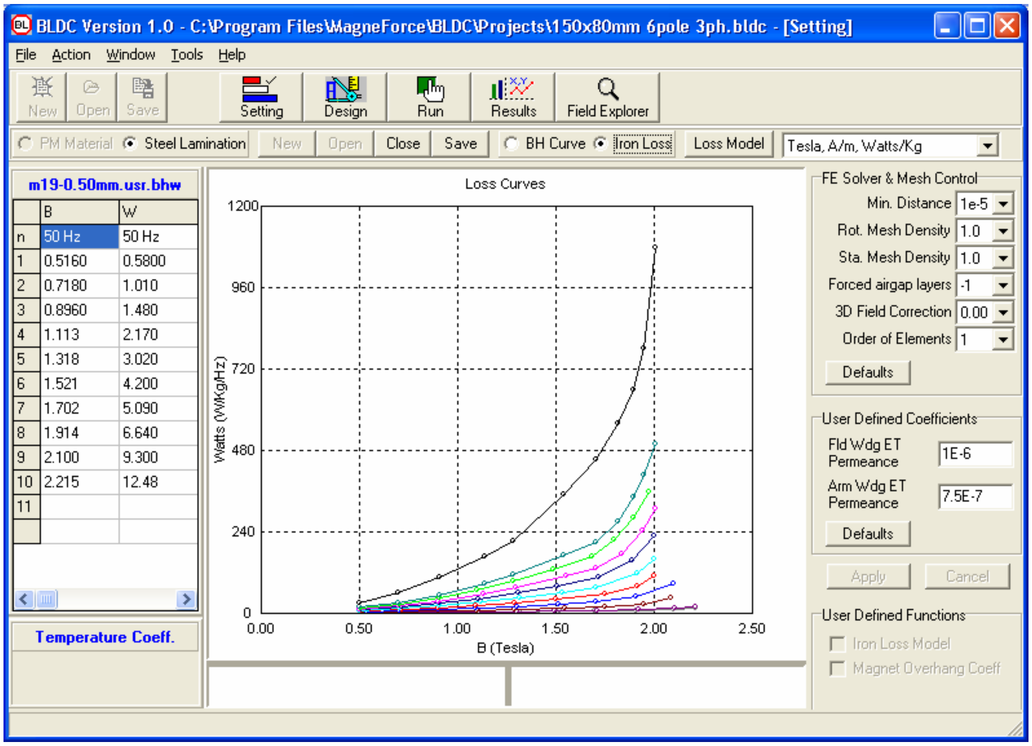
After modifying the material properties, you may click the SAVE button found along the top of the settings panel. Upon doing so, the program will open a dialog box requesting you to save the material with a new name. The system will not allow you to over-write a default material. If however you have opened a user defined material, the system confirms that you wish to over-write the existing material and does so.



A new material can be defined by closing any open material using the CLOSE button and then clicking the NEW button. The system will request a name and then open the material with blank tables. You may then populate the table with data points and when finished, save the new material. This new material will now be available to all MagneForce Simulators.

In the upper right corner of the settings panel is found the units selector drop down box. This selector box allows you to view the B-H curves and tables in the units of your choice. The available selections are Tesla & A/m & Watts/Kg or Tesla & KA/m & Watts/Kg or Tesla & A/m & Watts/Lb or Gauss & Oersted & Watts/Kg or KGauss & KOersted & Watts/Kg or Gauss & Oersted & Watts/Lb or KGauss & KOersted & Watts/Lb . Select the units with which you are most comfortable.

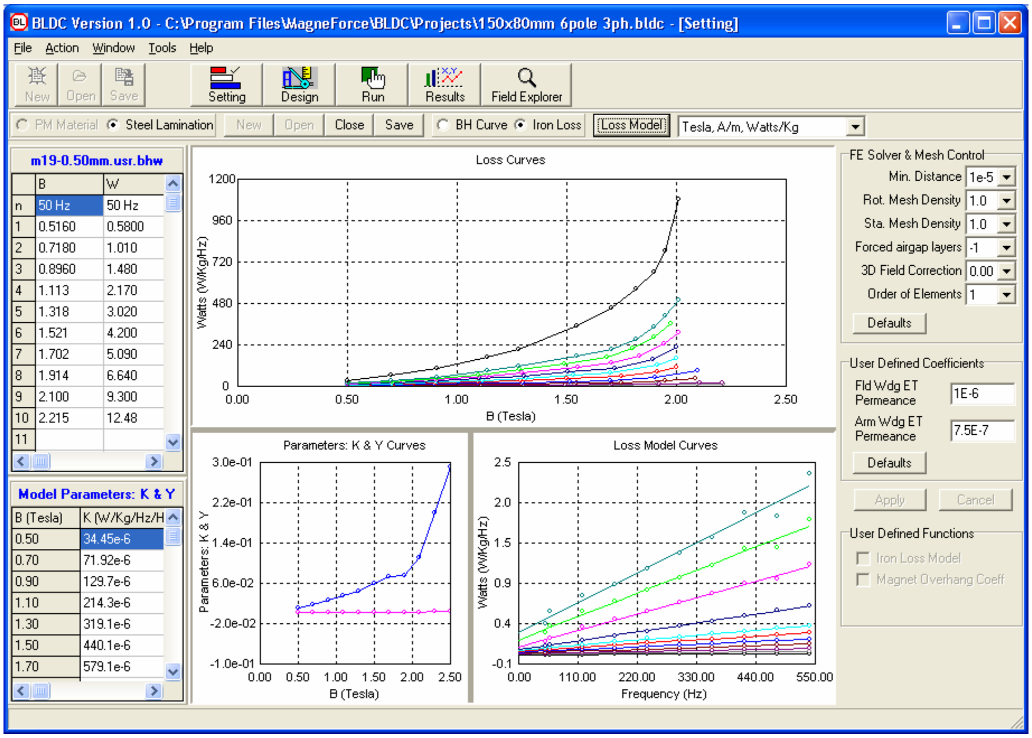
With STEEL LAMINATION still selected, click the IRON LOSS button.



A series of loss curves in Watts/Kg/Hz is displayed in both graphical and tabular format. Each of the curves is at a certain frequency. The table to the left indicates the frequency at which these losses have been determined. Each curve is represented by the pair of columns titled B and W with the same Frequency entry n. Use the scroll bars to see the table in its entirety. The values in the table can be adjusted and the results reflected in the curve to the right. Simply click on an entry and change it. The table will be immediately sorted and the graph updated. Additional data points can be added by using the scroll bars to position the cursor at the end of or to the right of the table. Simply enter your new values and the graphs and table will again be immediately updated.Additionally, the viewable size of the table and the graph area can be changed. Simply position your cursor on the area between the table and the graph area and click and drag to the desired size.

As with the B-H curve the units of the loss curves can be changed. In the upper right corner of the settings panel select from the drop down list the units you are most comfortable with. The available selections are Tesla & A/m & Watts/Kg or Tesla & KA/m & Watts/Kg or Tesla & A/m & Watts/Lb or Gauss & Oersted & Watts/Kg or KGauss & KOersted & Watts/Kg or Gauss & Oersted & Watts/Lb or KGauss & KOersted & Watts/Lb .

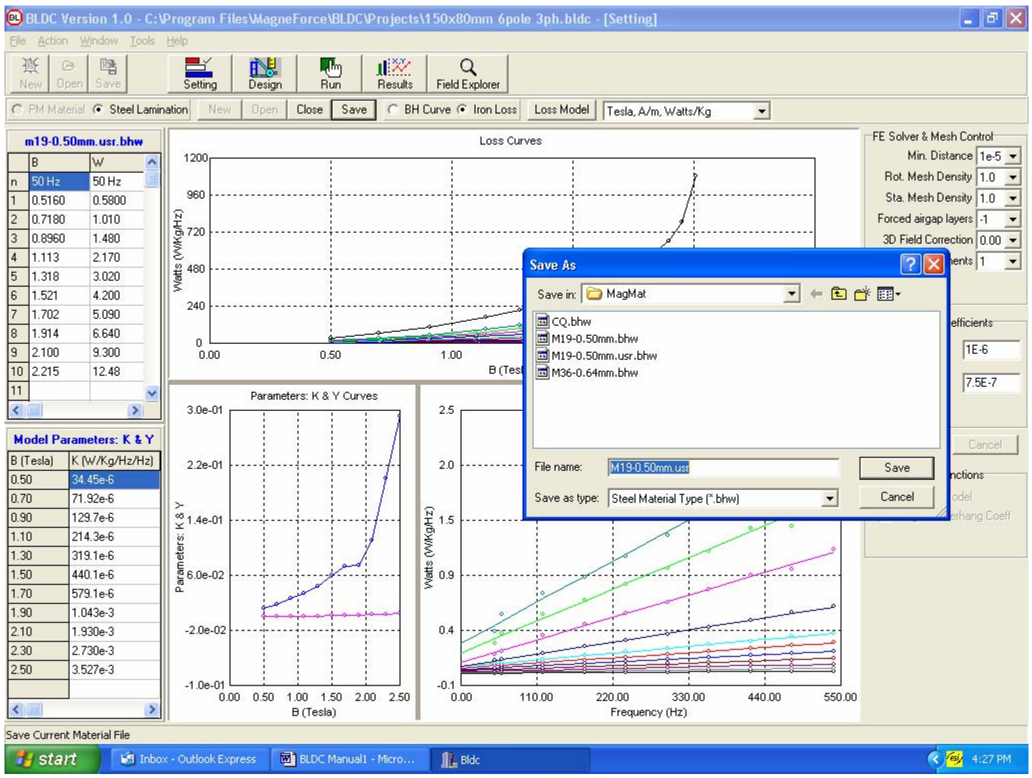
With STEEL LAMINATION and IRON LOSS still selected, click the LOSS MODEL button.



Two additional graphs and one table will appear on your screen. The graphs are the LOSS MODEL CURVES which plots Loss versus Frequency, and the K & Y PARAMETERS CURVES which plots K & Y versus Flux Density. The loss model curves are best fit curves to the associated data points which is the loss expressed in Watts/Kg/Hz vs Hz for a given flux density. The slope and Y intercept of these best fit curves are then the K and Y parameters to the left, which are plotted vs the peak flux density from a sinusoidal excitation. This loss model is used in the program's iron loss calculation. The table to the left contains the data points for the K & Y Parameters. The values in the table can be adjusted and the results reflected in the curves to the right. Simply click on an entry and change it. The table will be immediately sorted and the graph updated. Additional data points can be added by using the scroll bars to position the cursor at the end of the table. Simply enter your new values and the graph and table will again be immediately updated.

The viewable size of the table and the two graphs can be changed. Simply position your cursor on the area between either the table and the graphs or between the two graphs and click and drag to the desired size.

After modifying the material properties you may click the SAVE button along the top of the settings panel. Upon doing so the program will open a dialog box requesting you to save the material with a new name. The system will not allow you to over-write a default material. If however you have opened a user defined material, the system confirms that you wish to over-write the existing material and does so.



In the upper right corner of the settings panel is the units selector drop down box. This selector box allows you to view the B-H curves and tables in the units of your choice. The available selections are Tesla & A/m & Watts/Kg or Tesla & KA/m & Watts/Kg or Tesla & A/m & Watts/Lb or Gauss & Oersted & Watts/Kg or KGauss & KOersted & Watts/Kg or Gauss & Oersted & Watts/Lb or KGauss & KOersted & Watts/Lb . Select the units with which you are most comfortable.

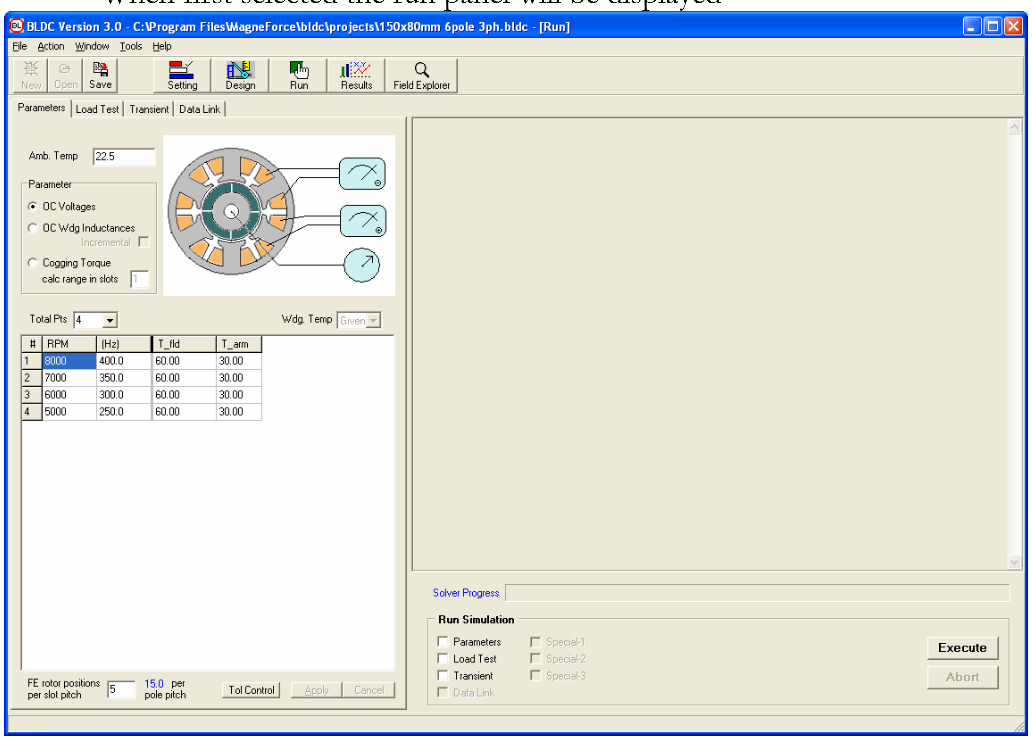
Chapter

7

The Run Panel

Once you have selected and described a machine, the run panel is used to select the type of simulation plus initiate the simulation process. Choices of simulation include parameter, load, transient, or data link. Once a type is selected, you may then select the number of data points, associated load parameters and finally begin the simulation.

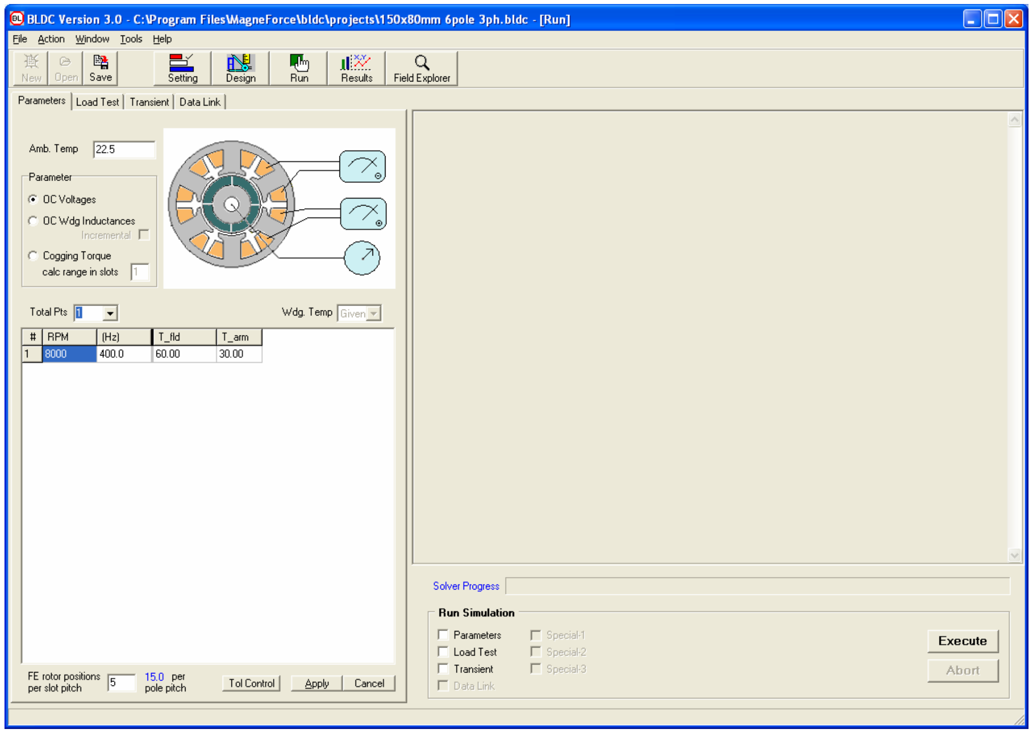
When first selected the run panel will be displayed



The run panel has four tabs to the left, a message area to the upper right and a check box field to the lower right. The tabs each correspond to a test of the machine under certain load conditions they are titled:

- Parameters.
- Load Test.
- Transient.
- Data Link.

PARAMETERS TAB



The parameters tab can be set to calculate one of three very important operational machine parameters described below. In many cases these open circuit parameters can go along way to helping a designer quantify his/her design, even before investigating the load parameters.

The tab has a space for

- **Amb. Temp** which is the ambient temperature of the machine in degrees Celsius.
- **OC Voltage** check box which should be checked if you are interested in obtaining the machine's Open Circuit Voltages Waveform.
- **OC Wdg Inductances** check box which should be checked if you are interested in obtaining the machine's Open Circuit Winding Inductances versus rotor position. BLDC can calculate either the apparent or incremental inductances. If you wish to calculate the incremental inductances simply check the box otherwise the apparent inductances will be calculated. In either case the complete set of self and mutual inductances will be calculated.
- **Cogging Torque** check box which should be checked if you are interested in obtaining the machine's cogging torque waveform versus rotor position. In the box enter the slot range over which you would like the cogging torque calculated.

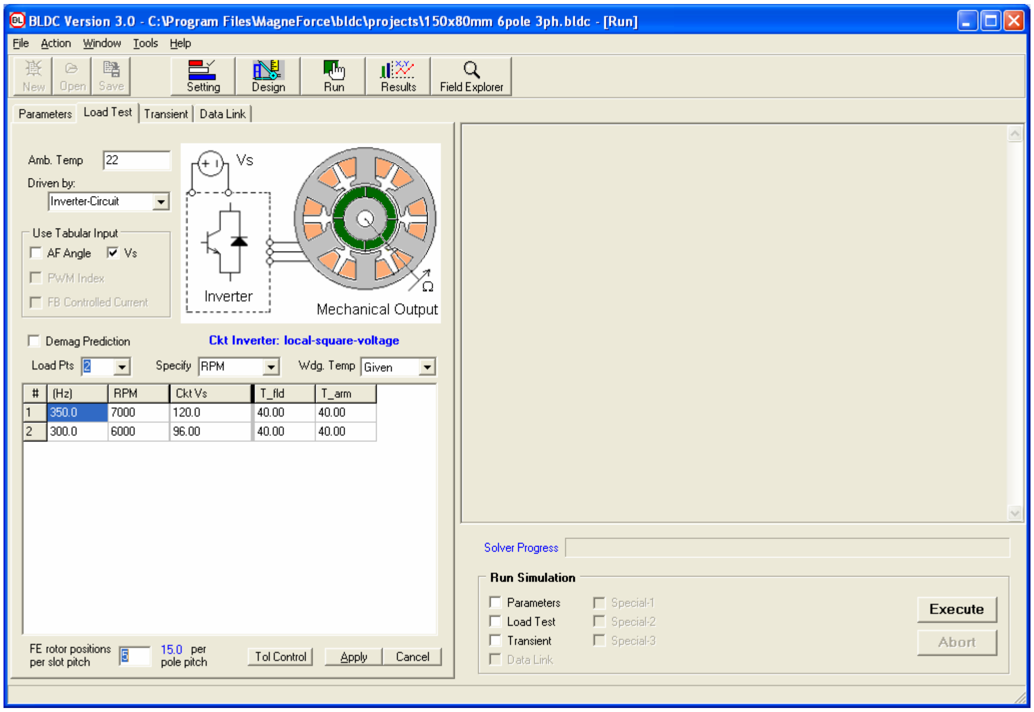
- **Total Pts** drop down box which sets the number of data points that the simulation will run for.
- **Wdg. Temp** field is not active on this tab.

Underneath this area is where the individual parameters are set for each load point. For the open circuit voltage and winding inductance test you will supply the following:

- **RPM** is the speed of the machine in revolutions per minute.
- **Hz** is the frequency of the machine in Hertz. This is a calculated value based upon the number of poles and the rpm.
- **T_fld** is the temperature of the field winding in Celsius.
- **T_arm** is the temperature of the armature winding in Celsius.

Below this area is a drop down box that specifies the finite element rotor positions per slot pitch. This parameter is used to take advantage of machine symmetry so that the number of finite element calculations can be kept to a minimum and thus decrease simulation time. To the right is a TOL CONTROL button that allows certain solution tolerances and simulation starting points to be changed. The default values for these parameters should work in almost all cases, therefore we do not recommend changing these values unless directed to by MagneForce technical support. To the right are the APPLY and CANCEL buttons that allow you to commit or abandon your changes.

LOAD TEST TAB



The load test tab layout is similar to the parameters tab, however this tab will simulate the machine under load conditions.

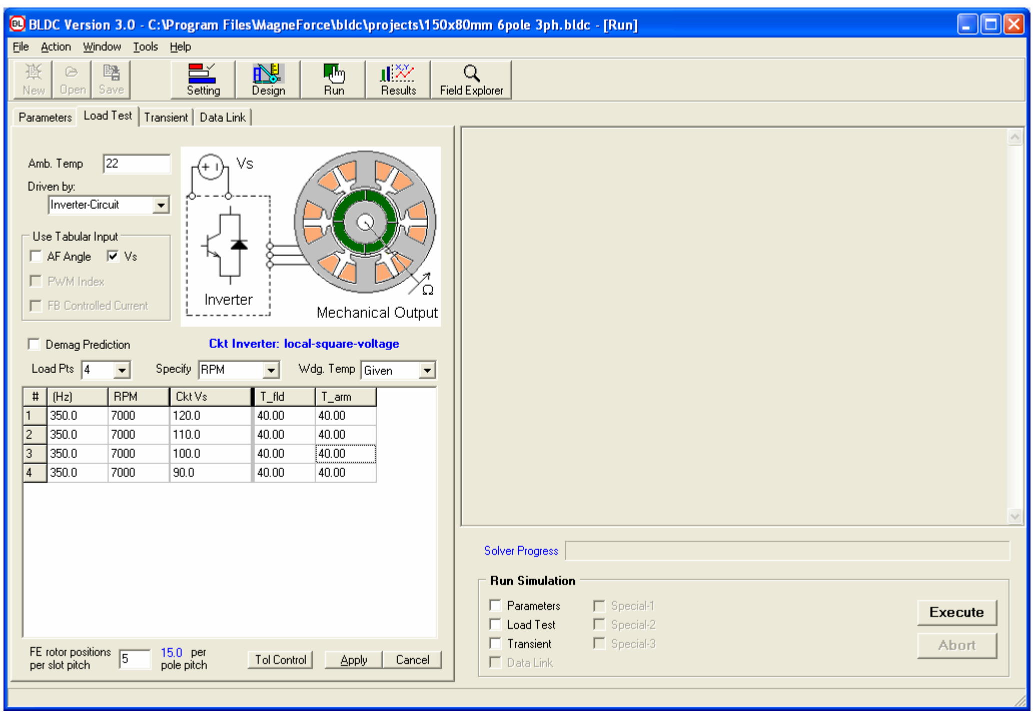
The parameters on this tab include:

- **Amb. Temp** which is the ambient temperature of the machine
- **Driven By** is a drop down box that can be set to one 4 choices, Inverter Circuit, AC Sine V, AC Square V or AC Sine A. These choices describe the type of excitation source used to drive the machine under consideration.
  - **Inverter Circuit** refers to the inverter drive circuit designed in the DRIVE CIRCUIT tab of the DESIGN panel.
  - **AC Sine V** specifies the machine to be run from an ideal AC sinusoidal voltage source, whose frequency and magnitude are specified in the DRIVE CIRCUIT tab of the DESIGN panel.
  - **AC Square V** specifies the machine to be run from an ideal AC square wave voltage source, whose frequency and magnitude are specified in the DRIVE CIRCUIT tab of the DESIGN panel.
  - **AC Sine A** specifies the machine to be run from an ideal AC sinusoidal current source, whose frequency and magnitude are specified in the DRIVE CIRCUIT tab of the DESIGN panel.
- **Use Tabular Input** contains a series of parameters that when checked will appear in the load point table below. The purpose of

this is to allow the user to override the settings of these individual parameters on the Drive Circuit tab and use the values in the load point table for each individual load. For example with Vs checked it is very easy to set up a load run with several points that differ only in supply voltage.

Below these parameters are several check boxes for additional parameters.

- **Demag Prediction** when checked the program will calculate any potential demagnetization of the permanent magnet material while under load.
- **Load Pts** field specifies the total number of load data points that you wish to simulate. After specifying the number of points here you will be given the opportunity later to further specify each load point.
- **Specify** is set to either RPM or TORQUE and controls whether speed or torque is being controlled during the simulation.
- **Wdg. Temp** is currently not implemented on this tab.

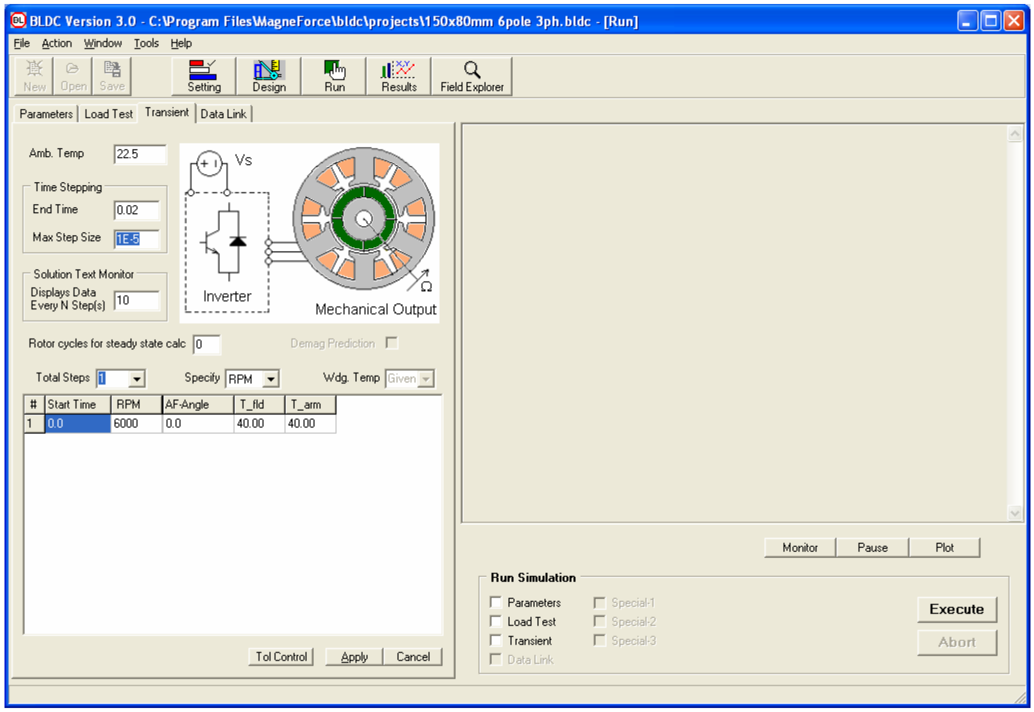


Below these parameters is the area where you further describe the load points selected above. Depending upon the selections from above the table may contain the following fields.

- **RPM** is the speed of the machine in revolutions per minute.
- **Hz** is the frequency of the machine calculated from the entry of the above RPM value.
- **Ckt Vs** is the source voltage of the DC supply, remember this value will override the value set on the Drive Circuit Tab.
- **T_fld** is the temperature of the field winding, in degrees Celsius.
- **T_arm** is the temperature of the armature winding, in degrees Celsius.

Below this area is a drop down box that specifies the Finite Element (FE) Rotor Positions Per Slot Pitch. This parameter is used to take advantage of machine symmetry so that the number of finite element calculations can be kept to a minimum and thus decrease simulation time. To the right is a TOL CONTROL button that allows certain solution tolerances and simulation starting points to be changed. The default values for these parameters should work in almost all cases, therefore we do not recommend changing these values unless directed to by MagneForce technical support. To the right are the APPLY and CANCEL buttons that allow you to commit or abandon your changes.

TRANSIENT TAB



The transient tab is similar to the load test tab in that it simulates machine performance under load however it uses a time stepping solution method that is capable of accurately calculating transient machine performance. The solution technique used here will allow accurate calculation of the actual machine parameters both during and after the transient has occurred. This simulation will require more solution time therefore it is not recommended for solution of a machine operating simply under steady state conditions.

The parameters on this tab include:

- **Amb. Temp** which is the ambient temperature of the machine.
- **End Time** is the ending time of the simulation, in seconds. Be sure to set this point an adequate amount beyond the Start Time of the last load in the load point table below
- **Max Step Size** is the maximum width, in seconds, of the time interval used during the simulation.
- **Display Progress Every N Steps** is a parameter used to control how often data points are output to the screen when monitoring the solution progress.
- **Rotor Cycles for Steady State Calc** specifies the number of AC cycles at the end of each load point from which the steady state parameters for that load point will calculated. For instance, setting this parameter to 2 will result in the data from the last 2 AC cycles

of each load point being used to calculate the steady state performance for each load point being studied.

- **Demag Prediction** not available on the Transient Tab.

Below these parameters are several boxes for additional parameters.

- **Total Steps** is the number of total events or transitions from one operating point to another during a solution.
- **Specify** is set to either RPM or TORQUE and controls whether speed or torque is being given during the simulation.
- **Wdg. Temp** is currently not implemented on this tab.

Below these parameters is the area where you further describe the operating points selected above. All operating points will require the following parameters:

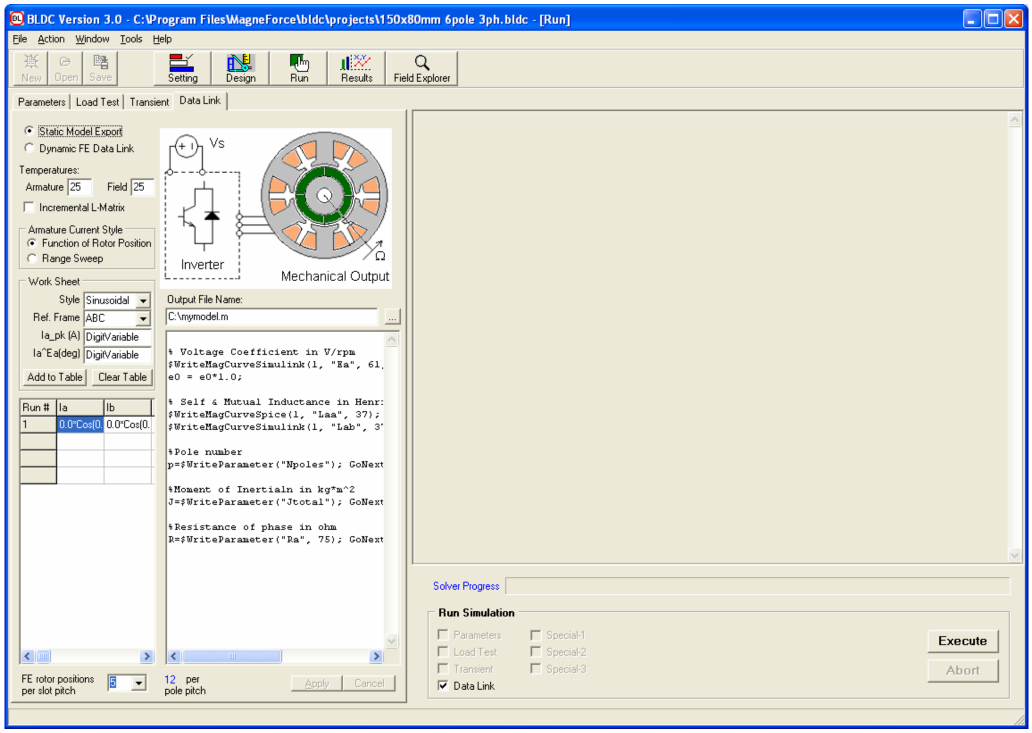
- **Start Time** is the time, in seconds, at which the operating point will take effect. Note this point should be before the end time as specified above.
- **RPM** is the speed of the machine in revolutions per minute.
- **AF Angle** is the advanced firing angle used during the simulation. This parameter will override the setting on the Drive Circuit tab of the DESIGN panel.
- **T_fld** is the temperature of the field winding, in degrees Celsius.
- **T_arm** is the temperature of the armature winding, in degrees Celsius.

Below this area is a field labeled

- **INITIAL RPM & Rotor Ang Deg** are the initial speed and rotor angle of the machine. This parameter is simply a starting point, and used only when TORQUE is the given parameter, as the speed will vary depending upon the operating point conditions.

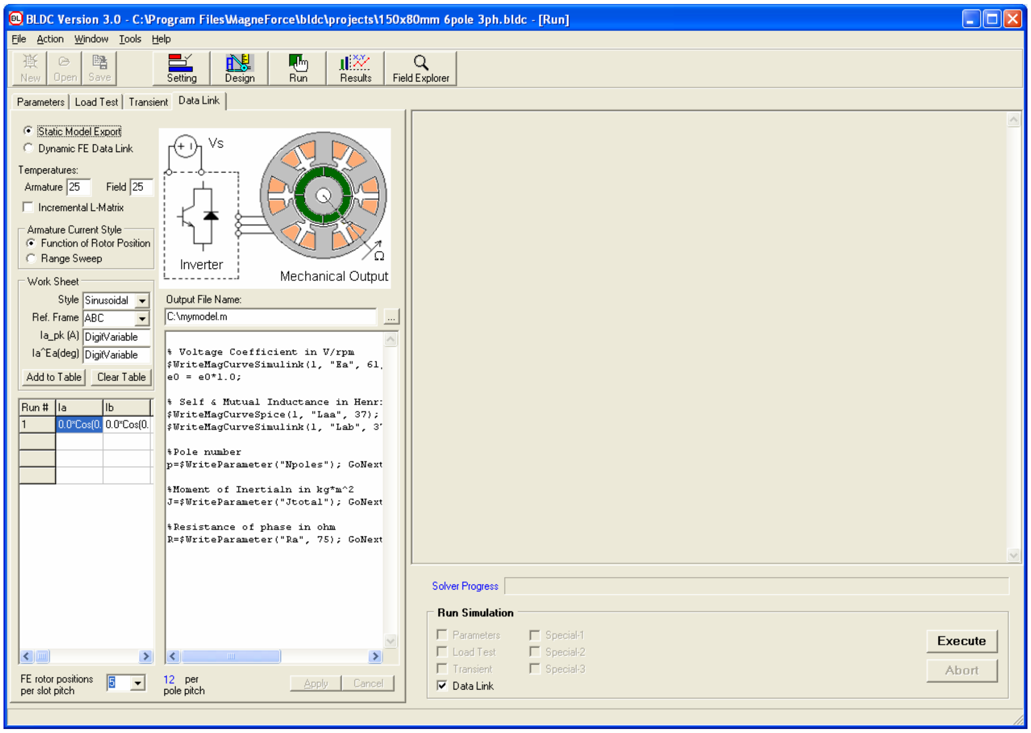
To the right is a TOL CONTROL button that allows certain solution tolerances and simulation starting points to be changed. The default values for these parameters should work in almost all cases, therefore we do not recommend changing these values unless directed to by MagneForce technical support. To the right are the APPLY and CANCEL buttons which allow you to commit or abandon your changes.

DATA LINK TAB



The Data Link tab is used to link MagneForce's powerful BLDC simulation environment with other popular 3rd party simulation software. For instance, rotating machines are almost always part of a larger mechanical and/or electrical system. If a complete simulation of this larger system is desired it can be done in Simulink, Sabre or other 3rd party simulation software. In this way these simulators can utilize the powerful finite element and parameter calculation ability of BLDC as part of their simulation environment to allow detailed simulations of entire systems to be carried out. BLDC can employ one of two different linking methods, static or dynamic. Using the static link, the complete magnetic parameters for all rotor positions and armature current values of interest are calculated ahead of the circuit simulation. Then during circuit simulation the 3rd party simulator will use a lookup table to gather the appropriate magnetic parameters for that instant in time. This differs from the dynamic link in which the 3rd party circuit simulator will "call" BLDC at the certain points during the circuit simulation passing the appropriate values to BLDC. BLDC will then perform the magnetic solution and pass back the magnetic parameters for that instant.

STATIC LINK



In the static data link method, BLDC pre-solves for the machine's magnetic parameters and produces an output data file that contains all of the desired data. The 3rd party simulator then reads this data file for the parameters of interest at the desired time step. The structure and content of the data file produced by BLDC is under the control of the user and is defined by completing the following fields:

Temperatures:

Armature: Temperature of armature in degrees Celsius

Field: Temperature of field in degrees Celsius

Armature Current Style:

Rotor Position Dependant: In this case the armature current is dependent upon the position of the rotor at any given time. The details of the armature current waveform are entered and described below in the work sheet section.

Range Sweep: In this case the armature current is dependent upon a set of fixed current values, the details of which are entered and described below in the work sheet section.

Work Sheet: This is the area where we describe the waveform and or magnitude/value of the armature current.

Style: Used in the Rotor Position Dependant case to describe the waveform of the armature current, choices are:

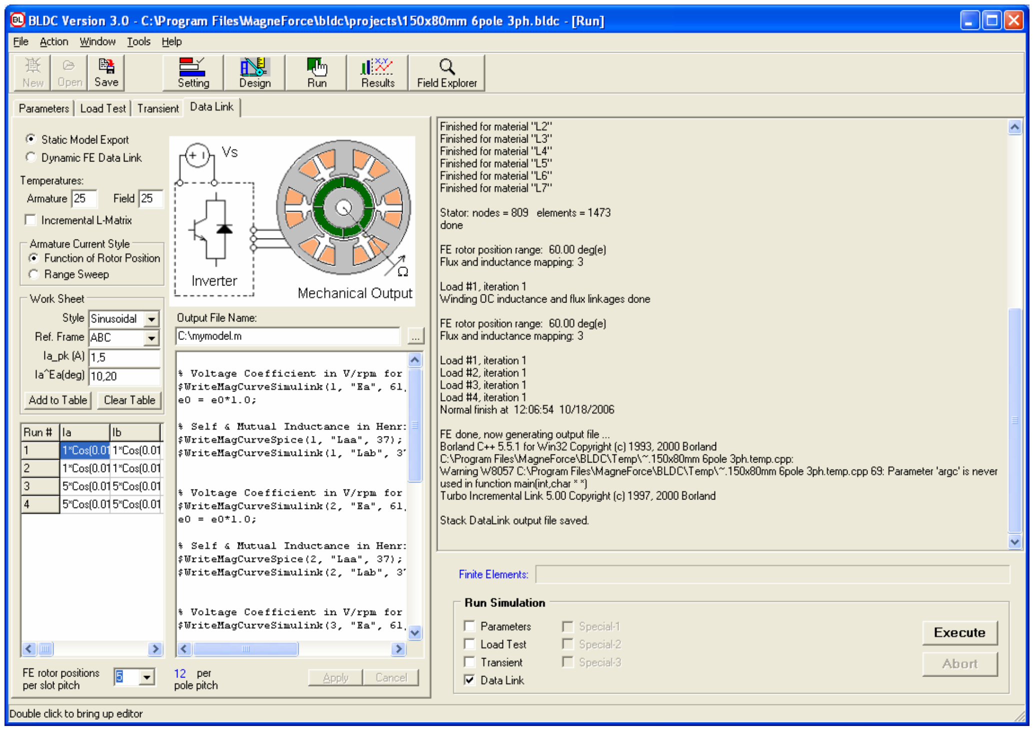
- **None:** Select when you wish to use the flux from the PM materials only and to ignore any armature reaction.
- **Sinusoidal:** Select when you wish to simulate using a sinusoidal armature current waveform in addition to the PM generated flux.
- **Square:** Select when you wish to simulate using a square wave armature current waveform in addition to the PM generated flux.

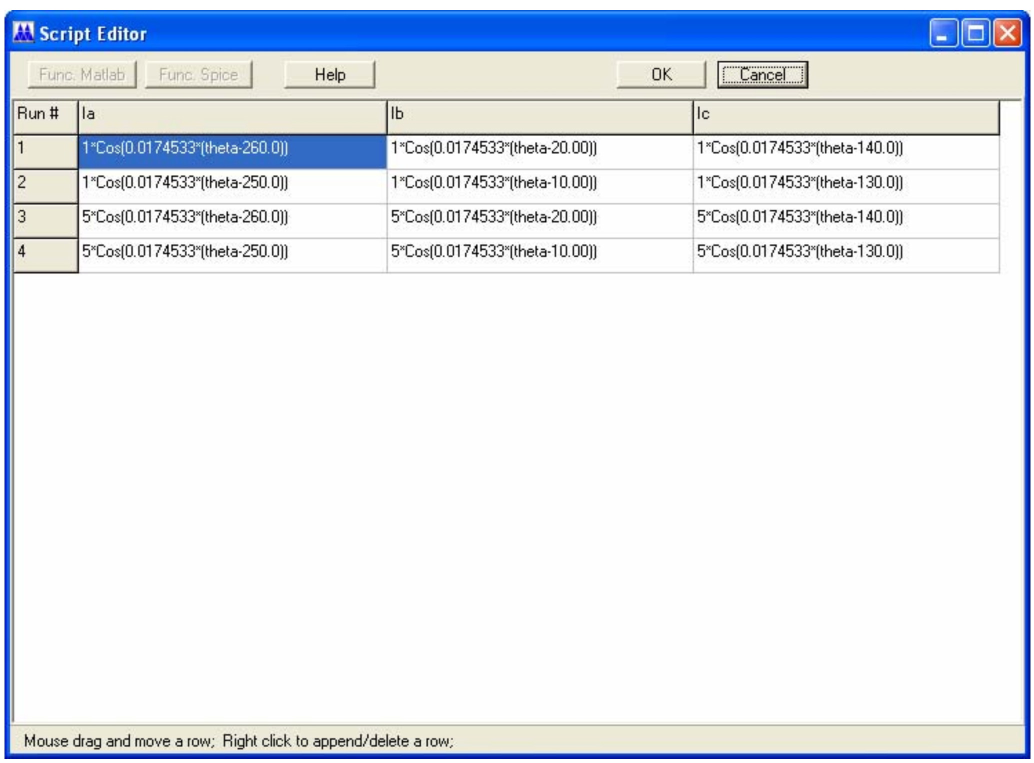
Ref Frame: Specifies the frame of reference that the calculations and data file will be produced in. Options are:

- **ABC:** refers to the normal time domain ABC reference frame. Multiple values can be entered, separated by a comma, so that BLDC will calculate the magnetic parameters at each of the specified current values. With this selection you will be required to enter the following:
  - **Ia pk (A):** peak value of phase A current
  - **Ia Ea (deg):** angle between the A phase current and resultant MMF.
- **DQ-1:** refers to the popular dq reference frame in which much control work is done. Multiple values can be entered, separated by a comma, so that BLDC will calculate the magnetic parameters at each of the specified current values.
  - **Id (A):** magnitude of q-axis current
  - **Iq (A)**: magnitude of d-axis current
- **DQ-2:** refers also to the dq refrence frame. Again multiple values can be entered, separated by a comma, so that BLDC will calculate the magnetic parameters at each of the specified current values. However with this selection you will describe the armature current by specifying the magnitude and phase of Is, the resultant vector formed by Id & Iq:
  - **Is (A):** magnitude of Is
  - **Is Er (deg):** angle of Is

After setting the above parameters be sure to click the button titled CLEAR TABLE and then click ADD TO TABLE. This will clear and then populate the armature current table below with the appropriate values from the above inputs. BLDC will populate the table with each combination of the above parameters. For example the figures below show 2 values entered for the magnitude of Ia and 2 values entered for the Ea angle. This will produce 4 lines in the table since each magnitude needs to be paired with each angle. This table can be thought of as the load point table from the parameter or load test tab. When the static link is executed BLDC will sequentially calculate the output data file using each of these 4 table entries as an input. In this way the output

file will consist of 4 distinct sections of output corresponding to each one of these inputs.

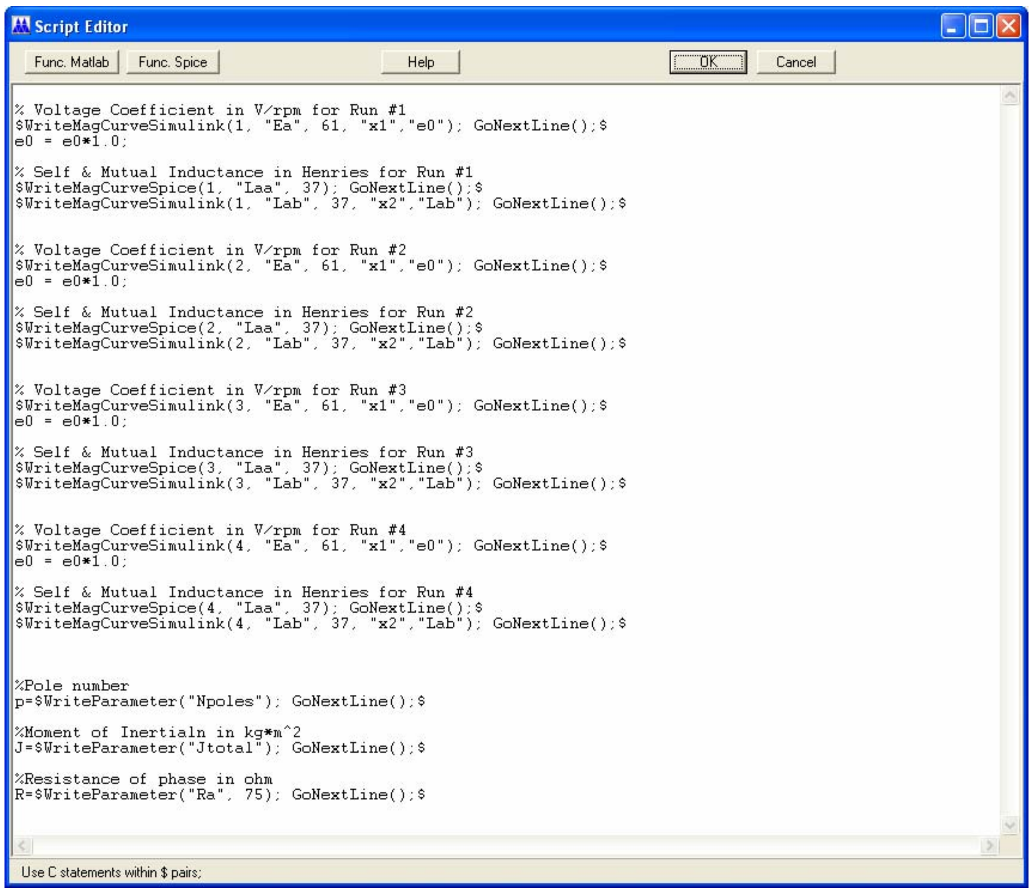




Output File Name:

In this section you will specify the parameters and structure of the output file that will form the link between BLDC and the 3rd party simulation package. MagneForce provides a number of built in functions that you can choose to form your output file. You also have the option of building your own functions and writing any "C" code to be executed as the program runs. In this box fill in the complete path and name for the location of the output data file. You may click the button labeled … to browse to the desired folder.

Double clicking the window pane below the output file name will produce the following script window.

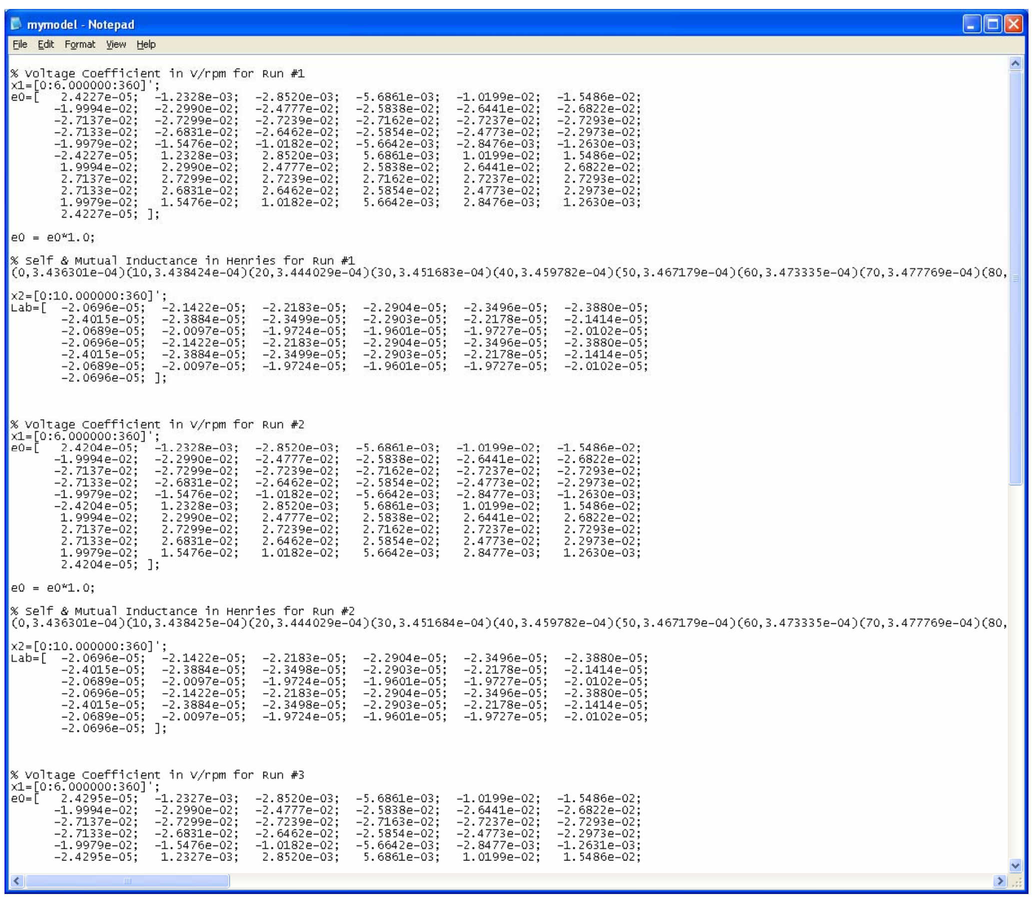


This is the script editor that is used to define the output file. Two simple rules or conditions apply to the script editor:

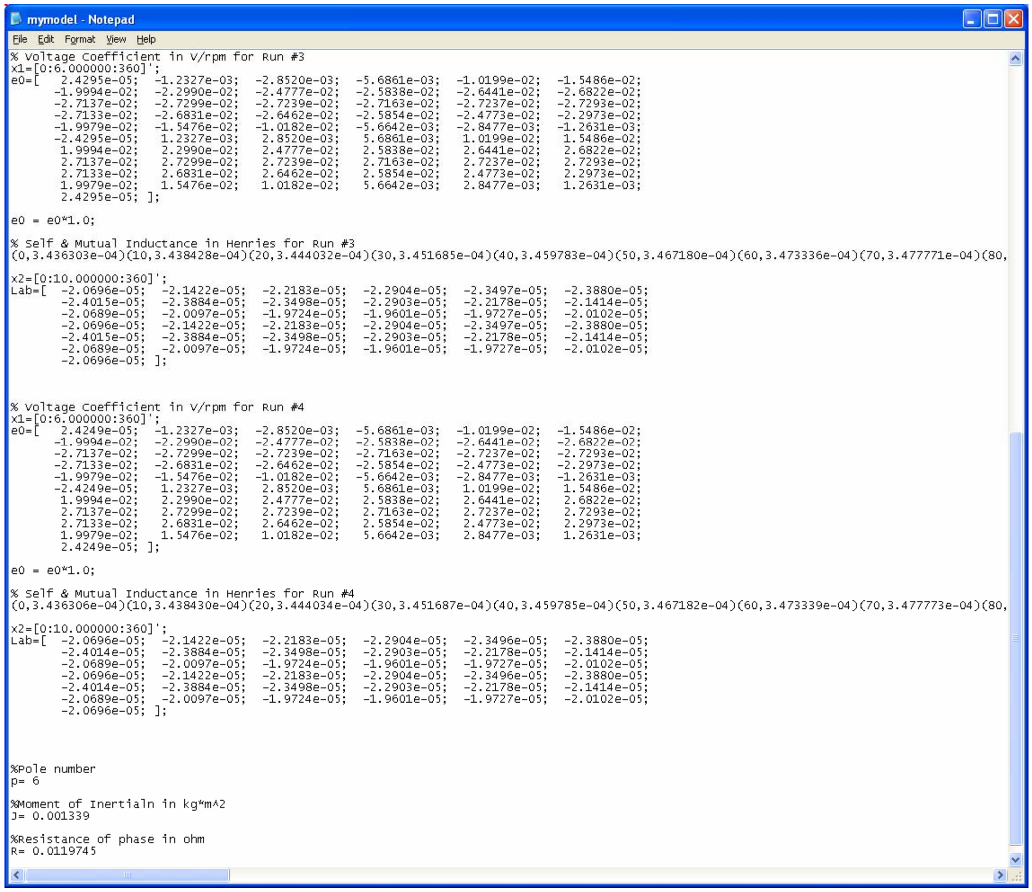
1. Any line not encased by $ signs will be written to the output data file exactly as it appears in this table.
2. Any line or group of code that is encased by a $ sign is interpreted as C++ code and will be executed and its result will be written to the output data file.

There are two methods to include results in the output data file. First MagneForce supplies many different functions for the most commonly exported parameters. These can be accessed by clicking the FUNC MATLAB or FUNC SPICE buttons located at the top of the window. The HELP button will give detailed explanations of each of the parameters in a given function as well as a sample of its correct usage. The second way to include results into the output data file is for the user to write his/her own C++ code encased again by the $ sign. Upon running the simulation the C code will be executed and the results written to the output file. This option will only be necessary if the desired parameter is not already included in one of the predefined MagneForce functions.

Upon successful completion of the script editor click the OK button and then click the EXECUTE button to run the actual simulation. A sample of the top half and bottom half of the output data file for the above data link example appears as the next two figures below. Notice how the lines not encased in the $ sign have been explicitly written to the data file while code between the $ signs has been executed and the results written to the file. Also note the corresponding section for each of the 4 distinct armature current runs.



```
mymodel - Notepad
File Edit Format View Help

% Voltage Coefficient in V/rpm for Run #1
x1=[0:6.000000:360]';
e0=[   2.4227e-05;  -1.2328e-03;  -2.8520e-03;  -5.6861e-03;  -1.0199e-02;  -1.5486e-02;
      -1.9994e-02;  -2.2990e-02;  -2.4777e-02;  -2.5838e-02;  -2.6441e-02;  -2.6822e-02;
      -2.7137e-02;  -2.7299e-02;  -2.7239e-02;  -2.7162e-02;  -2.7237e-02;  -2.7293e-02;
      -2.7133e-02;  -2.6831e-02;  -2.6462e-02;  -2.5854e-02;  -2.4773e-02;  -2.2973e-02;
      -1.9979e-02;  -1.5476e-02;  -1.0182e-02;  -5.6642e-03;  -2.8476e-03;  -1.2630e-03;
      -2.4227e-05;   1.2328e-03;   2.8520e-03;   5.6861e-03;   1.0199e-02;   1.5486e-02;
       1.9994e-02;   2.2990e-02;   2.4777e-02;   2.5838e-02;   2.6441e-02;   2.6822e-02;
       2.7137e-02;   2.7299e-02;   2.7239e-02;   2.7162e-02;   2.7237e-02;   2.7293e-02;
       2.7133e-02;   2.6831e-02;   2.6462e-02;   2.5854e-02;   2.4773e-02;   2.2973e-02;
       1.9979e-02;   1.5476e-02;   1.0182e-02;   5.6642e-03;   2.8476e-03;   1.2630e-03;
       2.4227e-05; ];

e0 = e0*1.0;

% Self & Mutual Inductance in Henries for Run #1
(0,3.436301e-04)(10,3.438424e-04)(20,3.444029e-04)(30,3.451683e-04)(40,3.459782e-04)(50,3.467179e-04)(60,3.473335e-04)(70,3.477769e-04)(80,

x2=[0:10.000000:360]';
Lab=[  -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3496e-05;  -2.3880e-05;
       -2.4015e-05;  -2.3884e-05;  -2.3499e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3496e-05;  -2.3880e-05;
       -2.4015e-05;  -2.3884e-05;  -2.3499e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05; ];


% Voltage Coefficient in V/rpm for Run #2
x1=[0:6.000000:360]';
e0=[   2.4204e-05;  -1.2328e-03;  -2.8520e-03;  -5.6861e-03;  -1.0199e-02;  -1.5486e-02;
      -1.9994e-02;  -2.2990e-02;  -2.4777e-02;  -2.5838e-02;  -2.6441e-02;  -2.6822e-02;
      -2.7137e-02;  -2.7299e-02;  -2.7239e-02;  -2.7162e-02;  -2.7237e-02;  -2.7293e-02;
      -2.7133e-02;  -2.6831e-02;  -2.6462e-02;  -2.5854e-02;  -2.4773e-02;  -2.2973e-02;
      -1.9979e-02;  -1.5476e-02;  -1.0182e-02;  -5.6642e-03;  -2.8477e-03;  -1.2630e-03;
      -2.4204e-05;   1.2328e-03;   2.8520e-03;   5.6861e-03;   1.0199e-02;   1.5486e-02;
       1.9994e-02;   2.2990e-02;   2.4777e-02;   2.5838e-02;   2.6441e-02;   2.6822e-02;
       2.7137e-02;   2.7299e-02;   2.7239e-02;   2.7162e-02;   2.7237e-02;   2.7293e-02;
       2.7133e-02;   2.6831e-02;   2.6462e-02;   2.5854e-02;   2.4773e-02;   2.2973e-02;
       1.9979e-02;   1.5476e-02;   1.0182e-02;   5.6642e-03;   2.8477e-03;   1.2630e-03;
       2.4204e-05; ];

e0 = e0*1.0;

% Self & Mutual Inductance in Henries for Run #2
(0,3.436301e-04)(10,3.438425e-04)(20,3.444029e-04)(30,3.451684e-04)(40,3.459782e-04)(50,3.467179e-04)(60,3.473335e-04)(70,3.477769e-04)(80,

x2=[0:10.000000:360]';
Lab=[  -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3496e-05;  -2.3880e-05;
       -2.4015e-05;  -2.3884e-05;  -2.3498e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3496e-05;  -2.3880e-05;
       -2.4015e-05;  -2.3884e-05;  -2.3498e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05; ];


% Voltage Coefficient in V/rpm for Run #3
x1=[0:6.000000:360]';
e0=[   2.4295e-05;  -1.2327e-03;  -2.8520e-03;  -5.6861e-03;  -1.0199e-02;  -1.5486e-02;
      -1.9994e-02;  -2.2990e-02;  -2.4777e-02;  -2.5838e-02;  -2.6441e-02;  -2.6822e-02;
      -2.7137e-02;  -2.7299e-02;  -2.7239e-02;  -2.7163e-02;  -2.7237e-02;  -2.7293e-02;
      -2.7133e-02;  -2.6831e-02;  -2.6462e-02;  -2.5854e-02;  -2.4773e-02;  -2.2973e-02;
      -1.9979e-02;  -1.5476e-02;  -1.0182e-02;  -5.6642e-03;  -2.8477e-03;  -1.2631e-03;
      -2.4295e-05;   1.2327e-03;   2.8520e-03;   5.6861e-03;   1.0199e-02;   1.5486e-02;
```



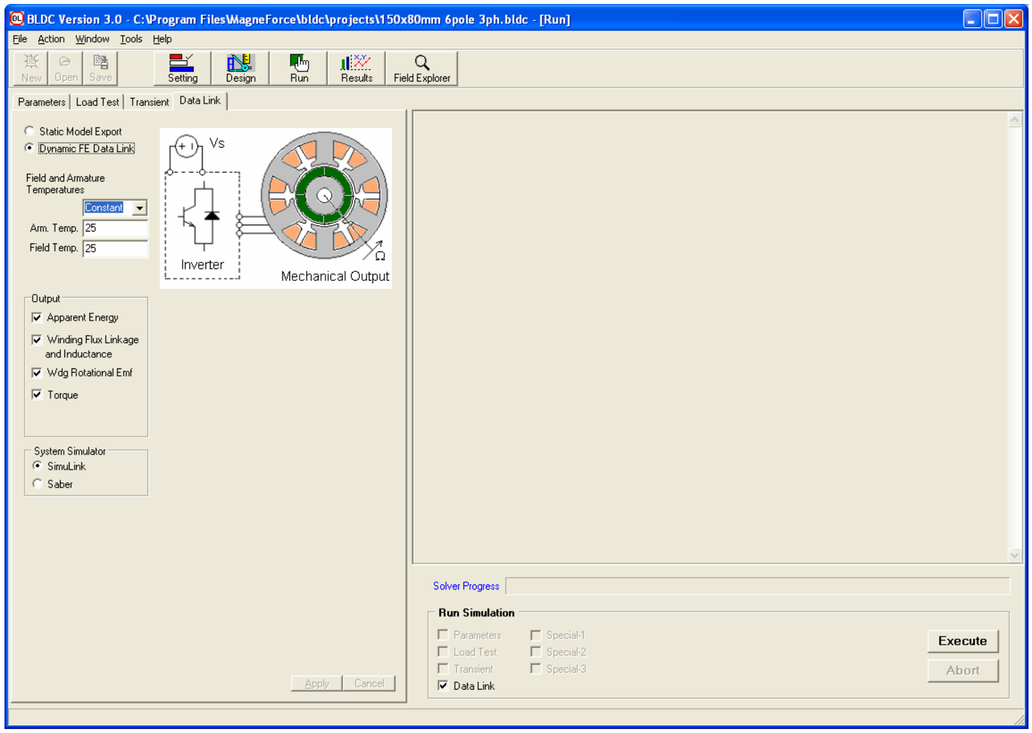
mymodel - Notepad

File Edit Format View Help

```
% Voltage Coefficient in V/rpm for Run #3
x1=[0:6.000000:360]';
e0=[   2.4295e-05;  -1.2327e-03;  -2.8520e-03;  -5.6861e-03;  -1.0199e-02;  -1.5486e-02;
      -1.9994e-02;  -2.2990e-02;  -2.4777e-02;  -2.5838e-02;  -2.6441e-02;  -2.6822e-02;
      -2.7137e-02;  -2.7299e-02;  -2.7239e-02;  -2.7163e-02;  -2.7237e-02;  -2.7293e-02;
      -2.7133e-02;  -2.6831e-02;  -2.6462e-02;  -2.5854e-02;  -2.4773e-02;  -2.2973e-02;
      -1.9979e-02;  -1.5476e-02;  -1.0182e-02;  -5.6642e-03;  -2.8477e-03;  -1.2631e-03;
      -2.4295e-05;   1.2327e-03;   2.8520e-03;   5.6861e-03;   1.0199e-02;   1.5486e-02;
       1.9994e-02;   2.2990e-02;   2.4777e-02;   2.5838e-02;   2.6441e-02;   2.6822e-02;
       2.7137e-02;   2.7299e-02;   2.7239e-02;   2.7163e-02;   2.7237e-02;   2.7293e-02;
       2.7133e-02;   2.6831e-02;   2.6462e-02;   2.5854e-02;   2.4773e-02;   2.2973e-02;
       1.9979e-02;   1.5476e-02;   1.0182e-02;   5.6642e-03;   2.8477e-03;   1.2631e-03;
       2.4295e-05; ];

e0 = e0*1.0;

% Self & Mutual Inductance in Henries for Run #3
(0,3.436303e-04)(10,3.438428e-04)(20,3.444032e-04)(30,3.451685e-04)(40,3.459783e-04)(50,3.467180e-04)(60,3.473336e-04)(70,3.477771e-04)(80,

x2=[0:10.000000:360]';
Lab=[  -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3497e-05;  -2.3880e-05;
       -2.4015e-05;  -2.3884e-05;  -2.3498e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3497e-05;  -2.3880e-05;
       -2.4015e-05;  -2.3884e-05;  -2.3498e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05; ];


% Voltage Coefficient in V/rpm for Run #4
x1=[0:6.000000:360]';
e0=[   2.4249e-05;  -1.2327e-03;  -2.8520e-03;  -5.6861e-03;  -1.0199e-02;  -1.5486e-02;
      -1.9994e-02;  -2.2990e-02;  -2.4777e-02;  -2.5838e-02;  -2.6441e-02;  -2.6822e-02;
      -2.7137e-02;  -2.7299e-02;  -2.7239e-02;  -2.7163e-02;  -2.7237e-02;  -2.7293e-02;
      -2.7133e-02;  -2.6831e-02;  -2.6462e-02;  -2.5854e-02;  -2.4773e-02;  -2.2973e-02;
      -1.9979e-02;  -1.5476e-02;  -1.0182e-02;  -5.6642e-03;  -2.8477e-03;  -1.2631e-03;
      -2.4249e-05;   1.2327e-03;   2.8520e-03;   5.6861e-03;   1.0199e-02;   1.5486e-02;
       1.9994e-02;   2.2990e-02;   2.4777e-02;   2.5838e-02;   2.6441e-02;   2.6822e-02;
       2.7137e-02;   2.7299e-02;   2.7239e-02;   2.7163e-02;   2.7237e-02;   2.7293e-02;
       2.7133e-02;   2.6831e-02;   2.6462e-02;   2.5854e-02;   2.4773e-02;   2.2973e-02;
       1.9979e-02;   1.5476e-02;   1.0182e-02;   5.6642e-03;   2.8477e-03;   1.2631e-03;
       2.4249e-05; ];

e0 = e0*1.0;

% Self & Mutual Inductance in Henries for Run #4
(0,3.436306e-04)(10,3.438430e-04)(20,3.444034e-04)(30,3.451687e-04)(40,3.459785e-04)(50,3.467182e-04)(60,3.473339e-04)(70,3.477773e-04)(80,

x2=[0:10.000000:360]';
Lab=[  -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3496e-05;  -2.3880e-05;
       -2.4014e-05;  -2.3884e-05;  -2.3498e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05;  -2.1422e-05;  -2.2183e-05;  -2.2904e-05;  -2.3496e-05;  -2.3880e-05;
       -2.4014e-05;  -2.3884e-05;  -2.3498e-05;  -2.2903e-05;  -2.2178e-05;  -2.1414e-05;
       -2.0689e-05;  -2.0097e-05;  -1.9724e-05;  -1.9601e-05;  -1.9727e-05;  -2.0102e-05;
       -2.0696e-05; ];



%Pole number
p= 6

%Moment of Inertialn in kg*m^2
J= 0.001339

%Resistance of phase in ohm
R= 0.0119745
```

The above file is now ready to be accessed by the 3rd party simulator.

DYNAMIC LINK

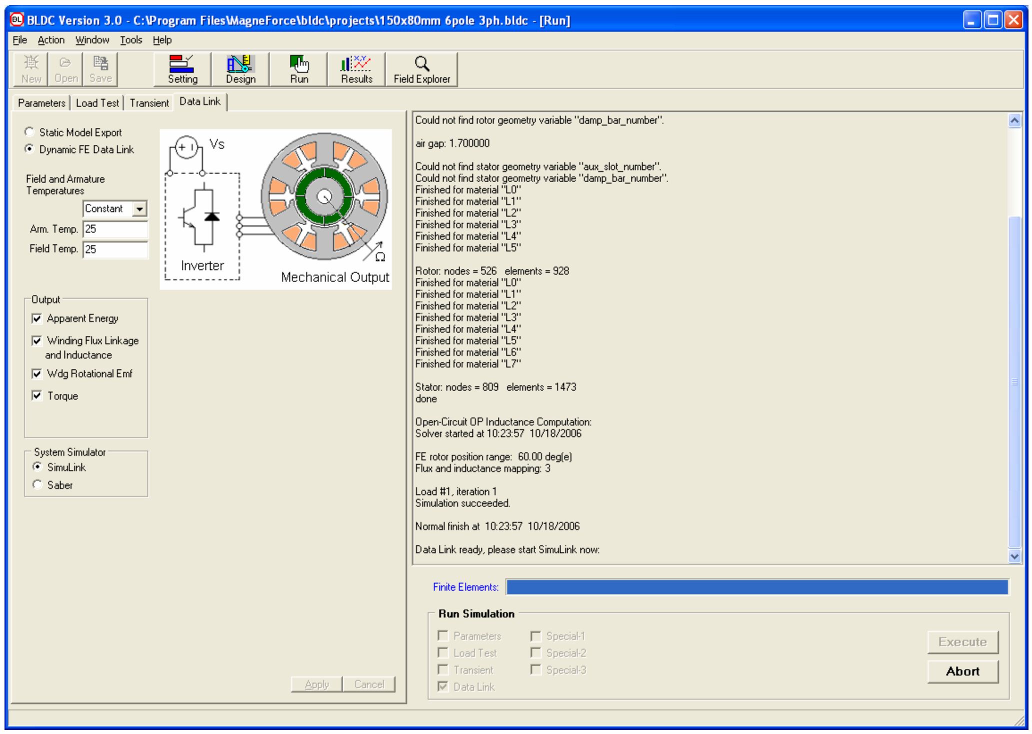


The parameters on this tab define the variables that will be passed between BLDC and whatever other simulator is employed:

- **Field and Armature Temperatures** is either set to Constant or Dynamic. If set to constant you must specify the actual temperatures. If set to dynamic this parameter is passed in from the other simulator for use by and within BLDC.
- **Apparent Energy** is a calculated parameter within BLDC and output to the other simulator. Select the check box to cause this parameter to be included in the output data files of BLDC.
- **Winding Flux Linkage and Inductance** is a calculated parameter within BLDC and output to the other simulator. Select the check box to cause this parameter to be included in the output data files of BLDC.
- **Winding Rotational EMF** is a calculated parameter within BLDC and output to the other simulator. Select the check box to cause this parameter to be included in the output data files of BLDC.
- **Torque** is a calculated parameter within BLDC and output to the other simulator. Select the check box to cause this parameter to be included in the output data files of BLDC.

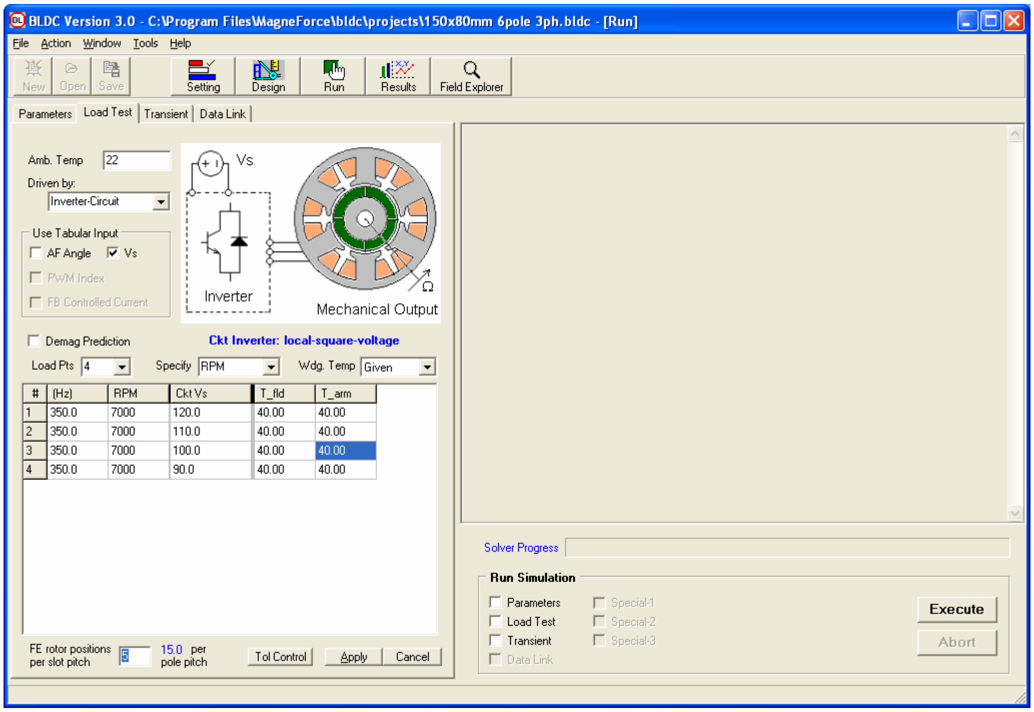
Below these parameters is a box to select the actual 3rd party simulator you are linking to either Simulink or Sabre.

Once the above parameters are set correctly, CLICK the EXECUTE button. BLDC will now prepare itself to be called by Simulink. A set of data files will be prepared and written and you will see the following screen:



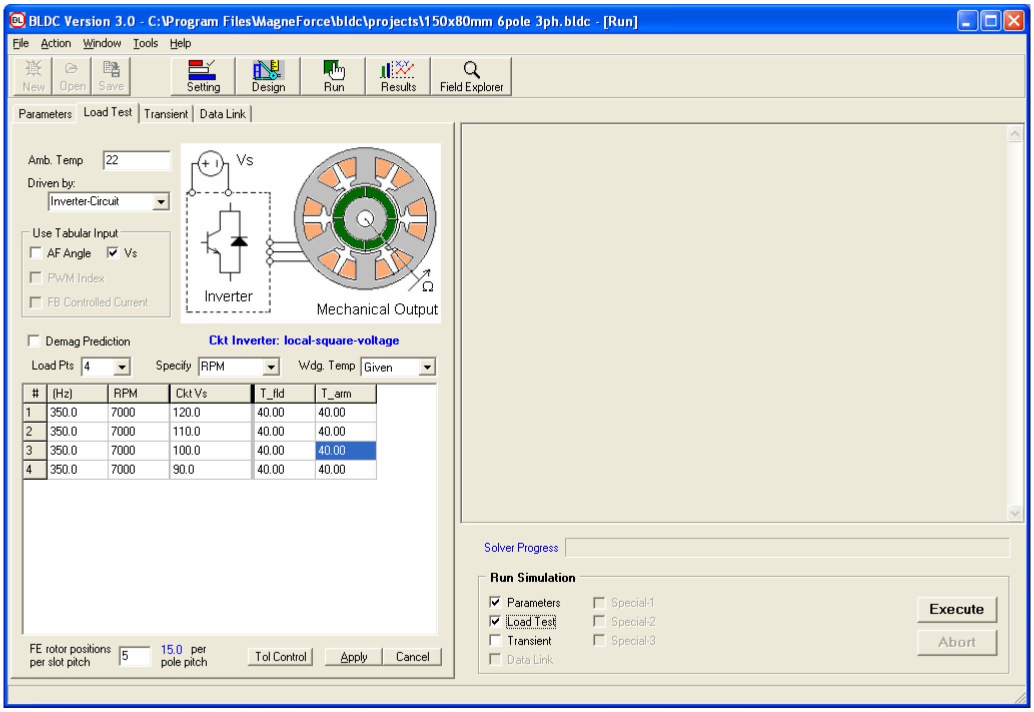
You may now minimize this window, start Simulink and perform the desired simulation. All viewing and plotting of results is done in Simulink for these simulations.

MESSAGE BOX



The right hand portion of this panel contains a message box in which the simulation progress is tracked. As the simulation proceeds you will see messages from the various BLDC components. For example when the meshing of the machine geometry is complete you will see a message indicating the number of nodes as well as elements created. This window contains a scroll bar to the right that allows you to scroll back through the status messages to review the programs actions. Below this window is a progress status bar that will indicate the progress of the finite element solver or the spice solver as appropriate.

RUN SIMULATION CHECK BOX



Under this message box is the RUN SIMULATION check box that allows you to select the simulation tests that you wish to run. Multiple simulation tests, with the exception of the Data Link test, can be checked simultaneously, for example you may select Parameters and Load Test and both tests will be performed. The EXECUTE button to the right hand side of this box begins the entire simulation process. Each test checked will be run and the results stored for later analysis as described in the next panel.

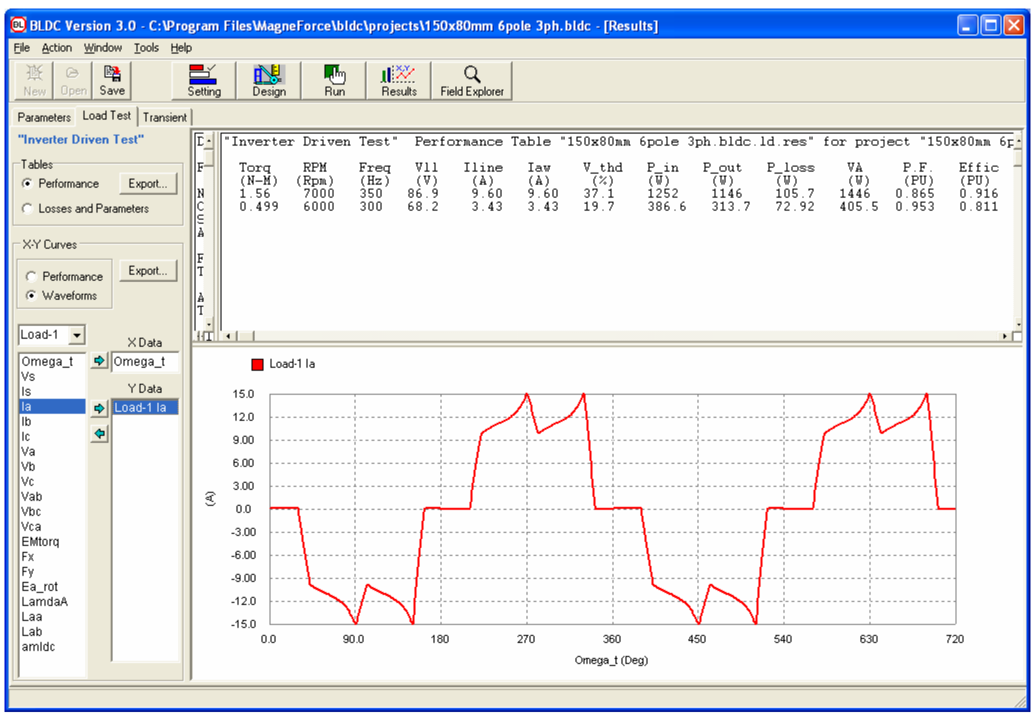
Chapter

8

The Results Panel

Upon simulation completion, the results panel is used to view the various parameterized output. Output includes the complete set of machine and load voltages and currents, as well as torque and power.

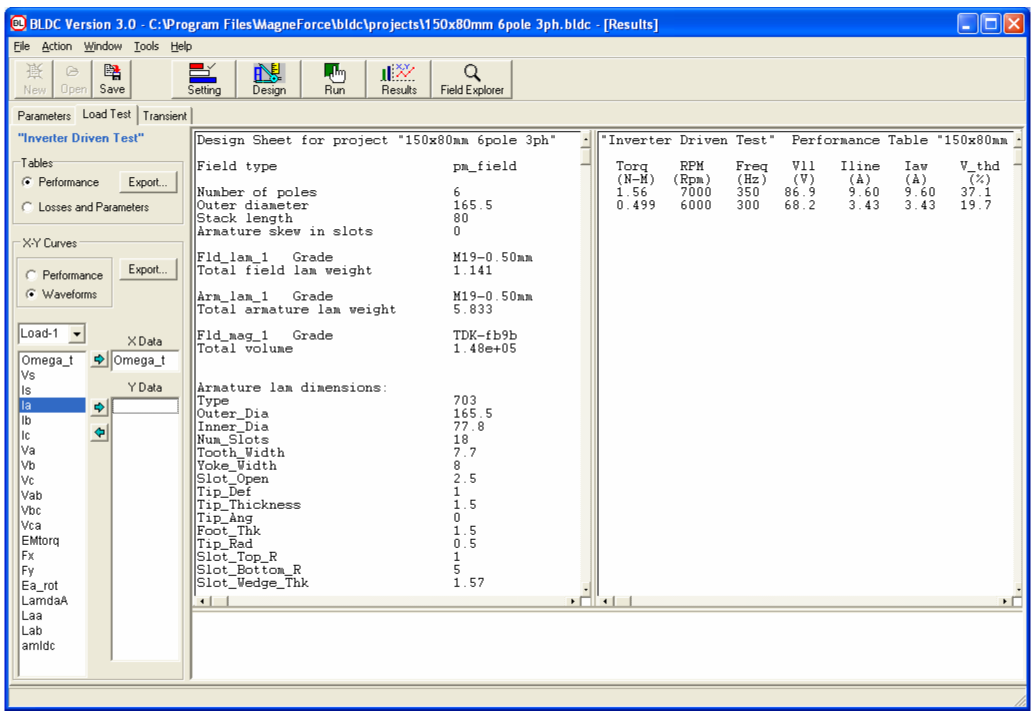
When first selected the results panel will be displayed:



This panel contains several tabs. In fact each type of load simulation has its own tab just as in the run panel. As you would expect, output data belonging to the parameter test will be found on the parameter tab of this panel and load test results will be found on the load tab. All tabs have essentially the same format.

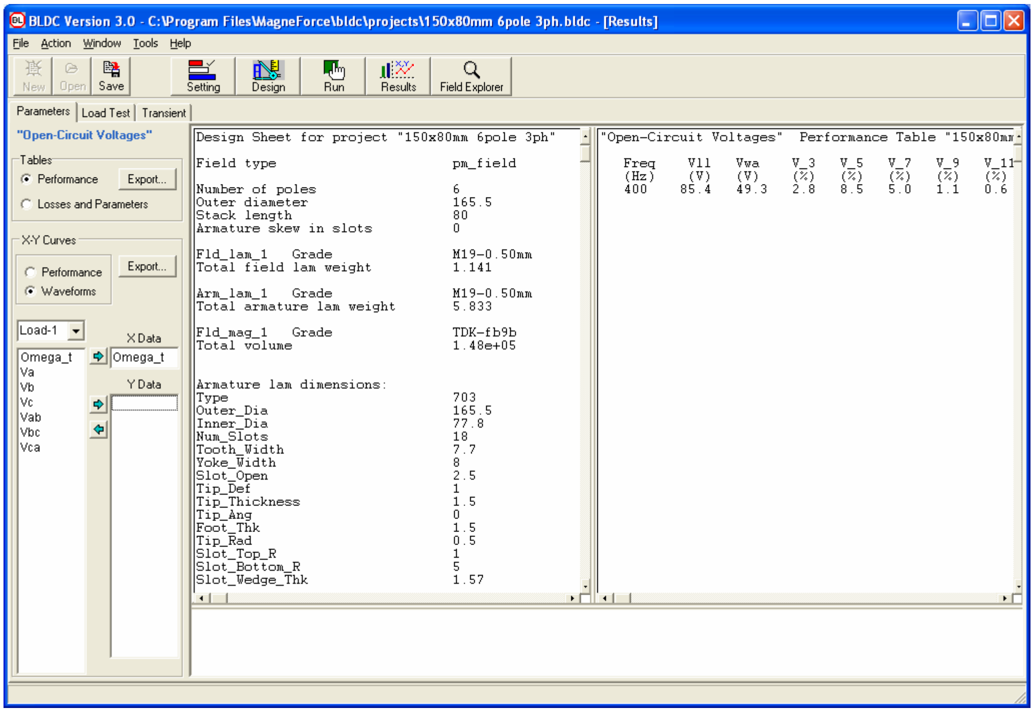
The left portion of the tab, from top to bottom, is the data selection area, it allows you to select the specific parameters you would like to view or export. This area has two sections one entitled Tables and the other X-Y Curves. The Tables section controls what will be seen in the tabular data output area to the right, while the X-Y Curves section controls what will be graphed in the area below.

The remaining portion of this tab contains a project design data sheet, tabular data output area and a graphical data output area. The design data sheet is a listing of all important design parameters entered previously on the settings and design panels. The tabular and graphical data output areas are where the selected results will be displayed in tabular and graphical format.



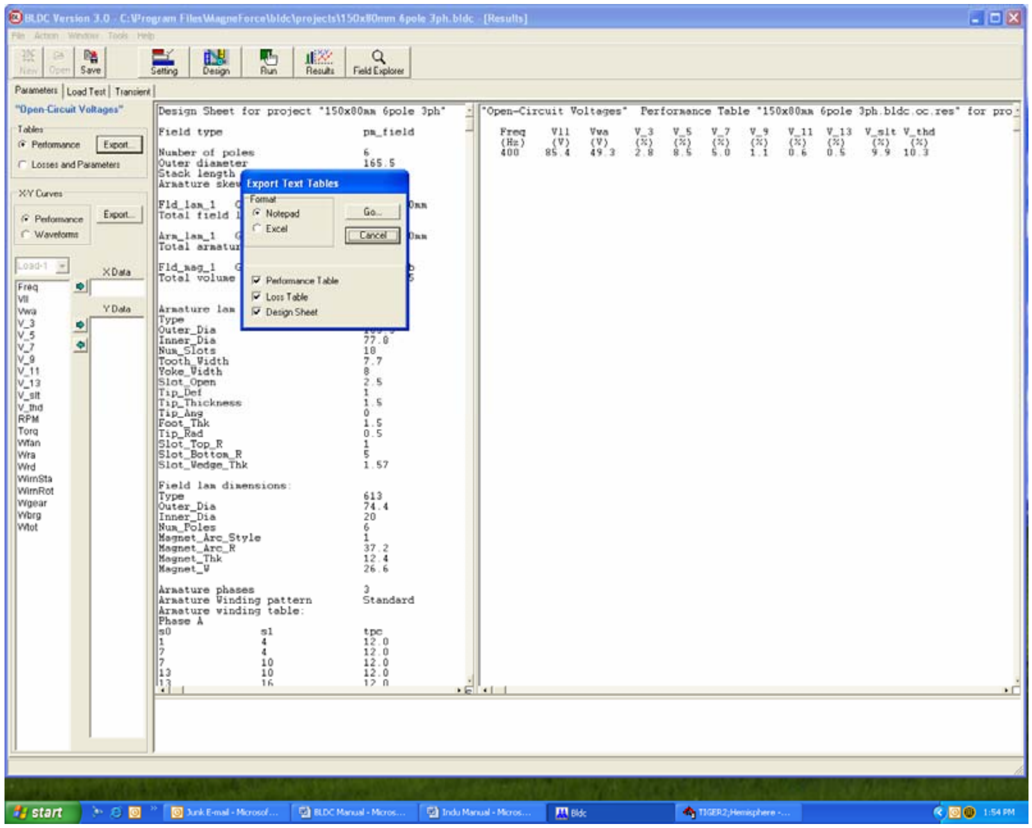
Each of these windows contain horizontal and vertical scroll bars, as appropriate, to allow you to view the entire data set. Additionally, the size of each of these windows can be adjusted by placing your cursor on the area between two windows and clicking and dragging to the desired size.

PARAMETERS TAB

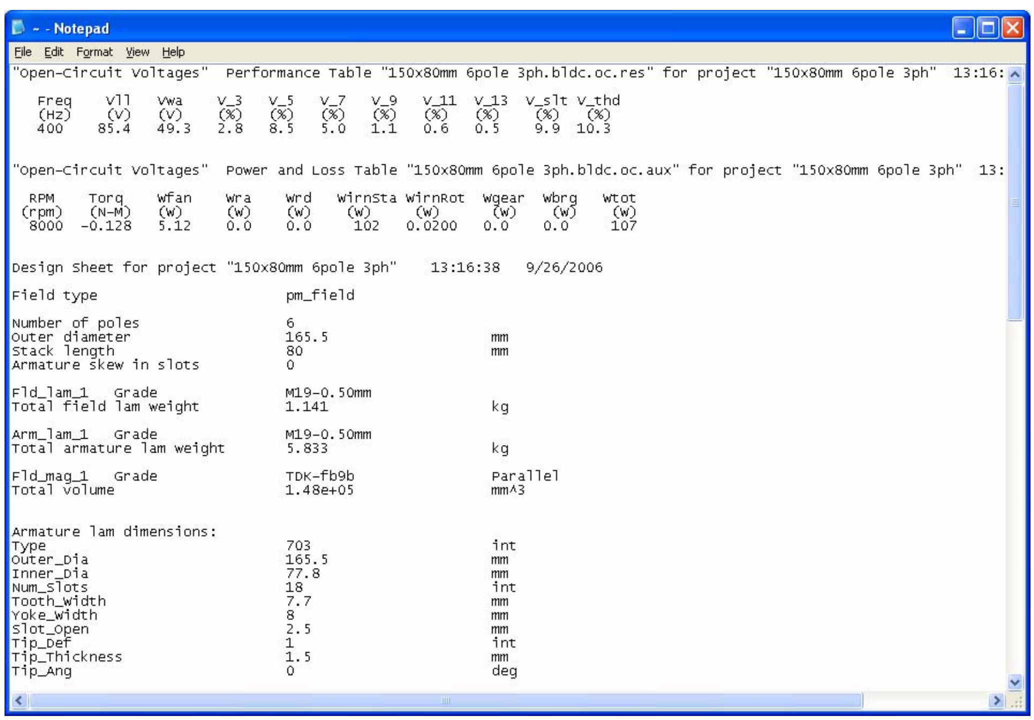


The name of the specific Parameter Test that was executed on the Run Panel will appear at the top of the data selection area. Below this is the Tables area that contains two choices and an export button:

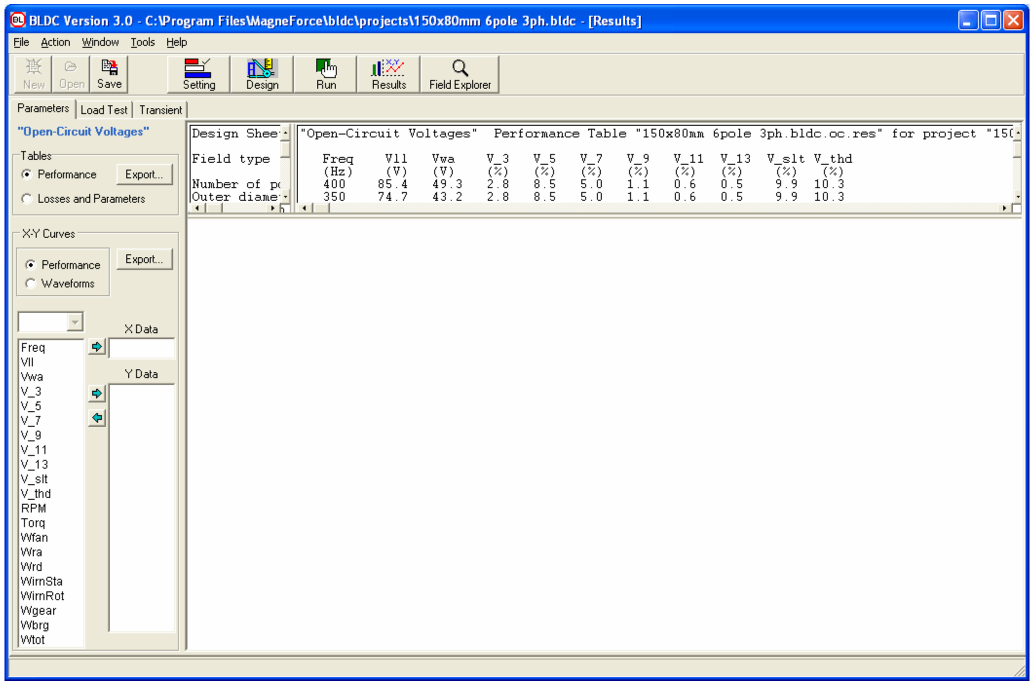
- **Performance,** when this is selected the performance parameters will be displayed in the tabular data output area to the right.
- **Loss Separation,** when this is selected the loss parameters will be displayed in the tabular data output area to the right.
- **Export** button is used to export the performance, loss data and/or project design data sheet. The output can be in either Microsoft Notepad, or Excel format.



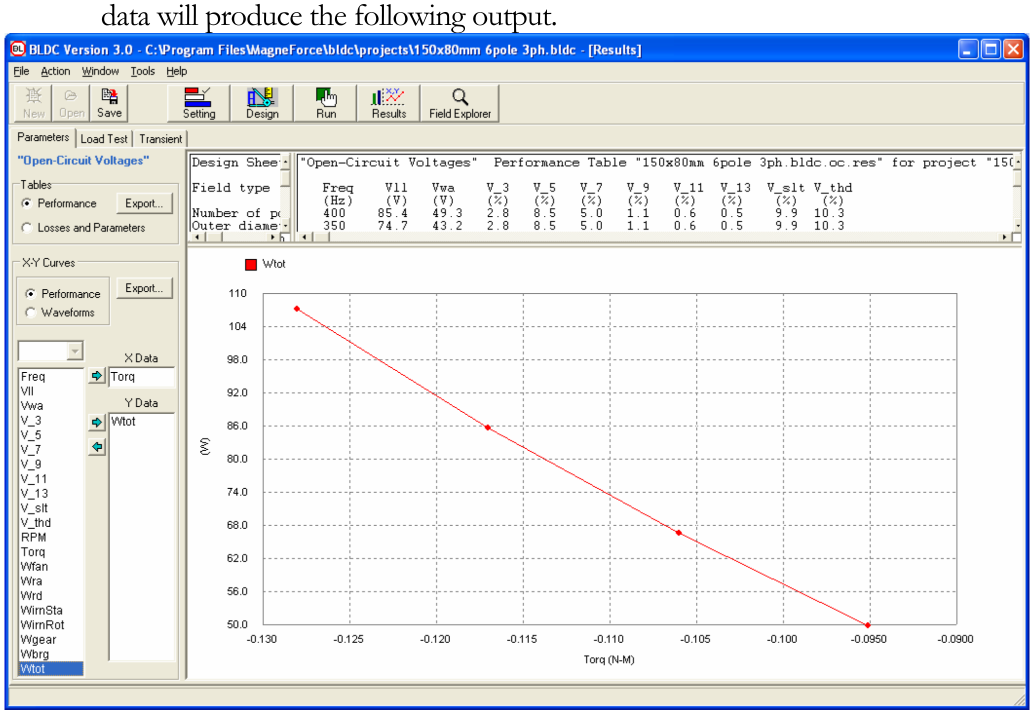
Selecting Export as described in the screen above will yield the following:



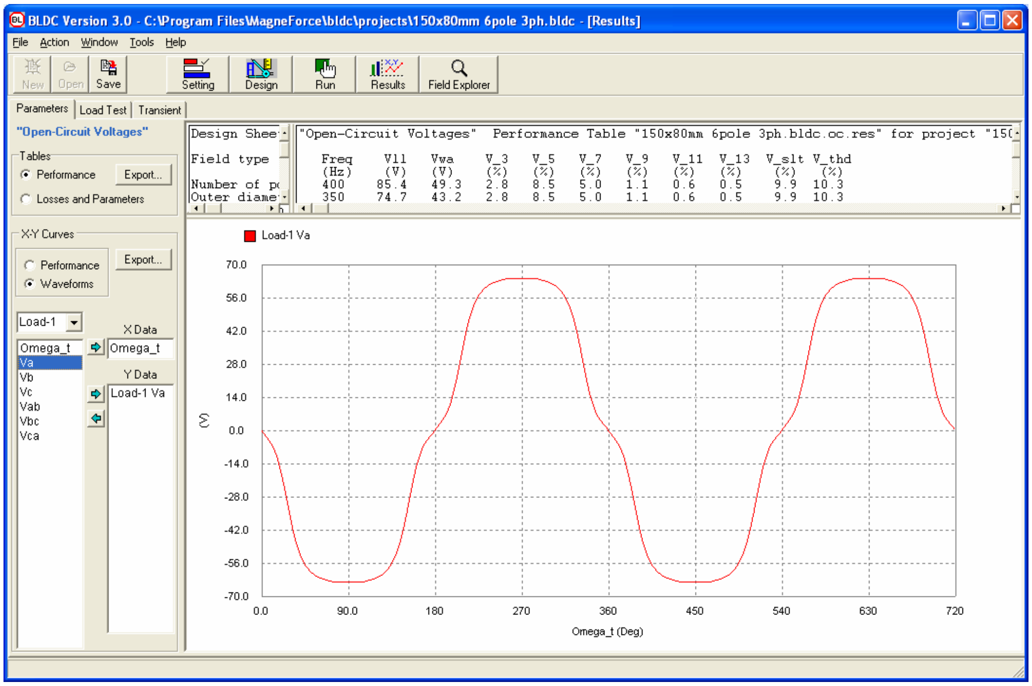
Below the Tables area is the X-Y Curves selection area. This section allows you to select the parameters to be graphed. It contains two choices and an export button along with a list of parameters that may be graphically displayed:



Selecting **Parameters** and Torq for the X-axis data and Wtot for the Y-axis data will produce the following output.



Selecting **Waveforms** will allow you to graph these machine parameters versus time. For instance, phase A open circuit voltage can be displayed as:

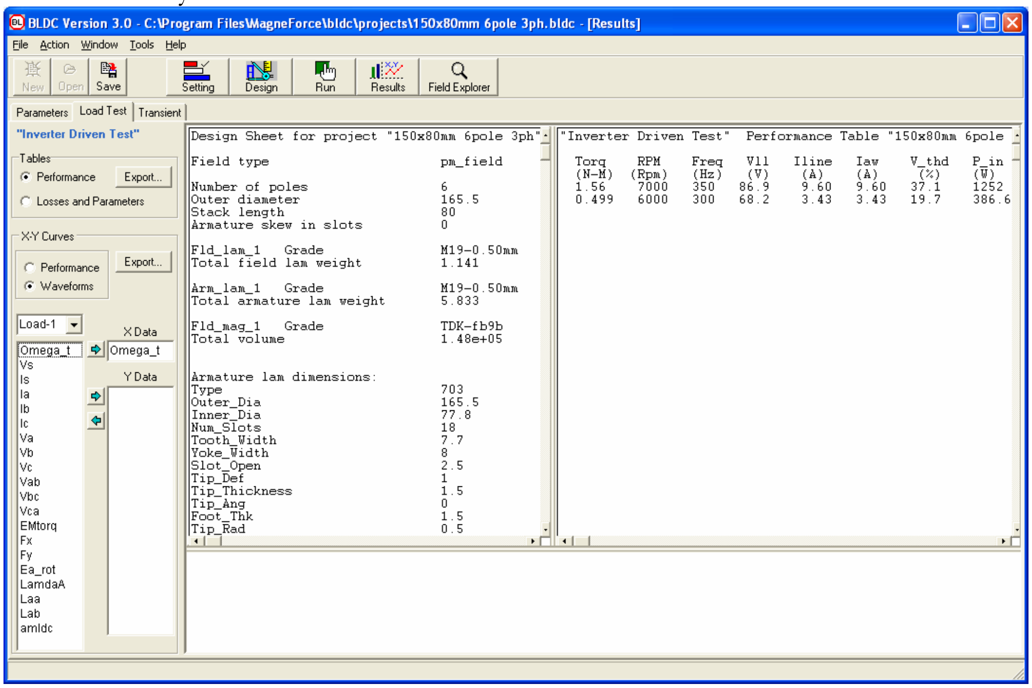


The drop down box containing Load-1 can be set to any of the load points specified on the Parameters tab of the Run panel. In this way you can graph the same machine parameter for different load points and/or different parameters for the same or different load points.

This section also contains an **Export** button which can be used to export the graphical data. The output can be in either Microsoft Notepad or Excel.

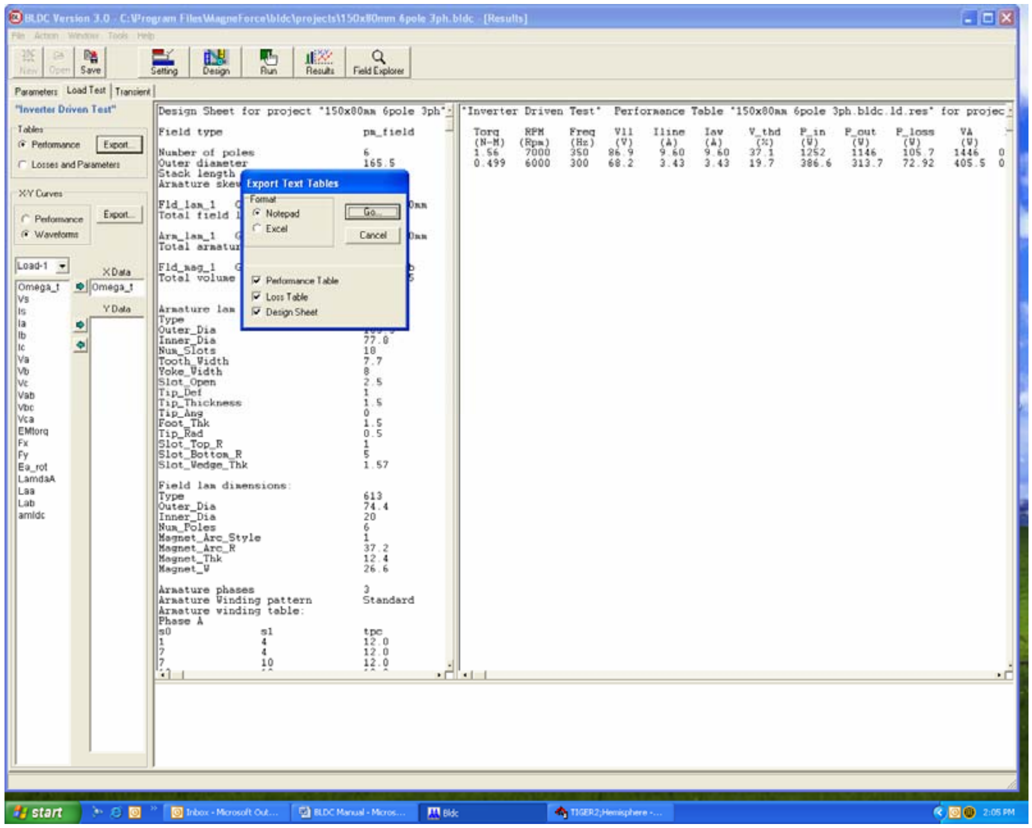
LOAD TEST TAB

The layout of the Load Test Tab is similar to the Parameters Tab.

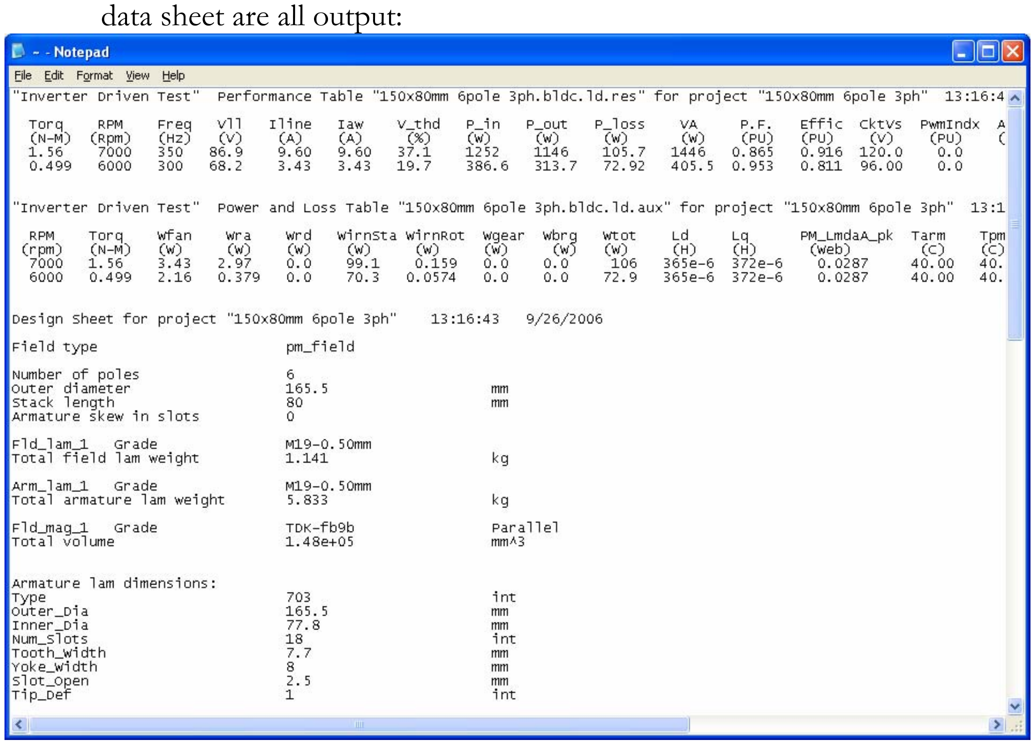


The name of the specific Load Test which was executed on the Run Panel will appear at the top of the data selection area. Below this is the Tables area that contains two choices and an export button:

- **Performance,** when this is selected the performance parameters will be displayed in the tabular data output area to the right.
- **Loss Separation,** when this is selected the loss parameters will be displayed in the tabular data output area to the right.
- **Export** button is used to export the performance, loss data and/or project design data sheet. The output can be in either Microsoft Notepad or Excel.

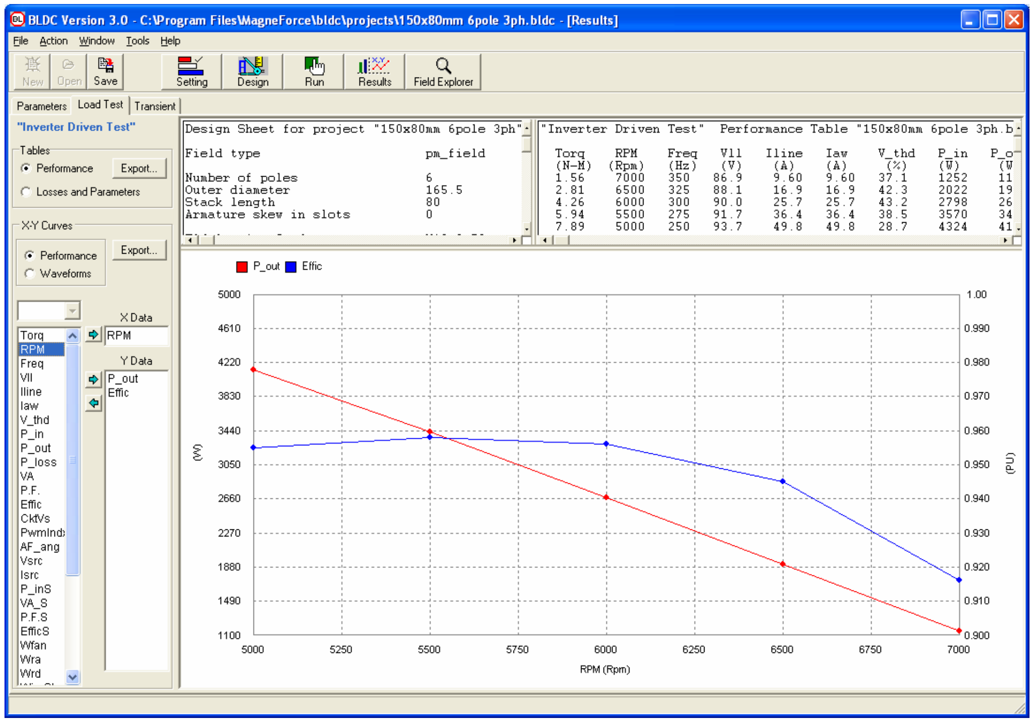


Selecting Export as described in the screen above will yield the following screen. Notice that the performance data, loss separation data and design data sheet are all output:

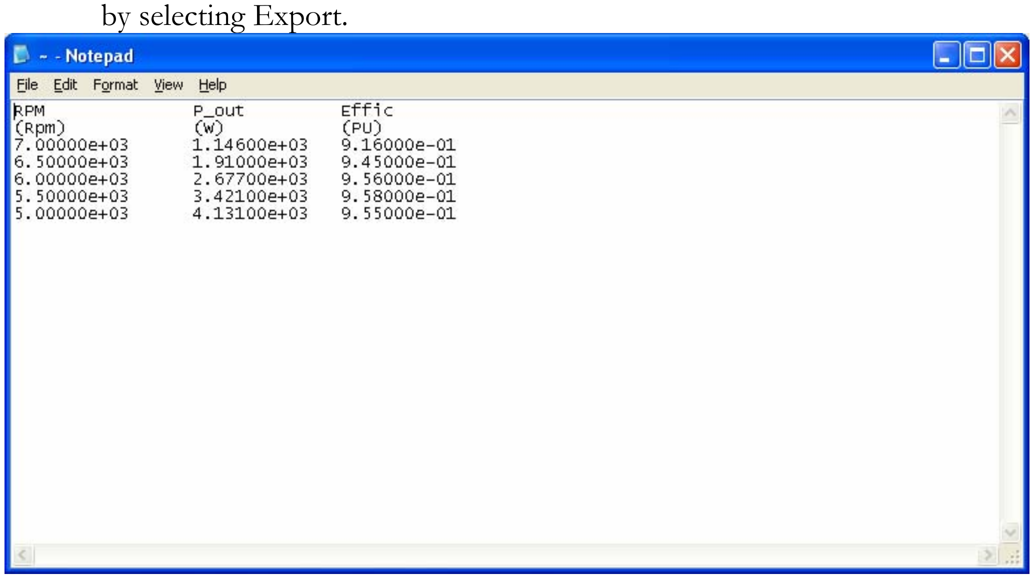


```
"Inverter Driven Test"  Performance Table "150x80mm 6pole 3ph.bldc.ld.res" for project "150x80mm 6pole 3ph"  13:16:4

  Torq    RPM    Freq   Vll    Iline   Iaw    V_thd   P_in   P_out   P_loss   VA     P.F.    Effic  CktVs  PwmIndx  A
 (N-M)  (Rpm)   (Hz)   (V)     (A)    (A)     (%)    (W)     (W)     (W)    (W)    (PU)    (PU)    (V)    (PU)    (
 1.56    7000   350   86.9    9.60   9.60    37.1   1252   1146    105.7   1446   0.865   0.916  120.0    0.0
 0.499   6000   300   68.2    3.43   3.43    19.7   386.6  313.7   72.92   405.5  0.953   0.811  96.00    0.0


"Inverter Driven Test"  Power and Loss Table "150x80mm 6pole 3ph.bldc.ld.aux" for project "150x80mm 6pole 3ph"  13:1

  RPM    Torq    Wfan    Wra    Wrd   WirnSta WirnRot  Wgear  Wbrg   Wtot    Ld      Lq     PM_LmdaA_pk  Tarm   Tpm
 (rpm)  (N-M)    (W)     (W)    (W)     (W)     (W)     (W)    (W)    (W)     (H)     (H)      (Web)      (C)    (C)
 7000   1.56    3.43    2.97    0.0    99.1    0.159   0.0    0.0    106   365e-6  372e-6     0.0287     40.00  40.
 6000   0.499   2.16    0.379   0.0    70.3    0.0574  0.0    0.0    72.9  365e-6  372e-6     0.0287     40.00  40.


Design Sheet for project "150x80mm 6pole 3ph"   13:16:43   9/26/2006

Field type                        pm_field

Number of poles                   6
Outer diameter                    165.5                    mm
Stack length                      80                       mm
Armature skew in slots            0

Fld_lam_1   Grade                 M19-0.50mm
Total field lam weight            1.141                    kg

Arm_lam_1   Grade                 M19-0.50mm
Total armature lam weight         5.833                    kg

Fld_mag_1   Grade                 TDK-fb9b                 Parallel
Total volume                      1.48e+05                 mm^3


Armature lam dimensions:
Type                              703                      int
Outer_Dia                         165.5                    mm
Inner_Dia                         77.8                     mm
Num_Slots                         18                       int
Tooth_Width                       7.7                      mm
Yoke_Width                        8                        mm
Slot_Open                         2.5                      mm
Tip_Def                           1                        int
```

Below the Tables area is the X-Y Curves selection area. This section allows you to select the parameters to be graphed. It contains two choices and an export button along with a list of parameters that may be graphically displayed:

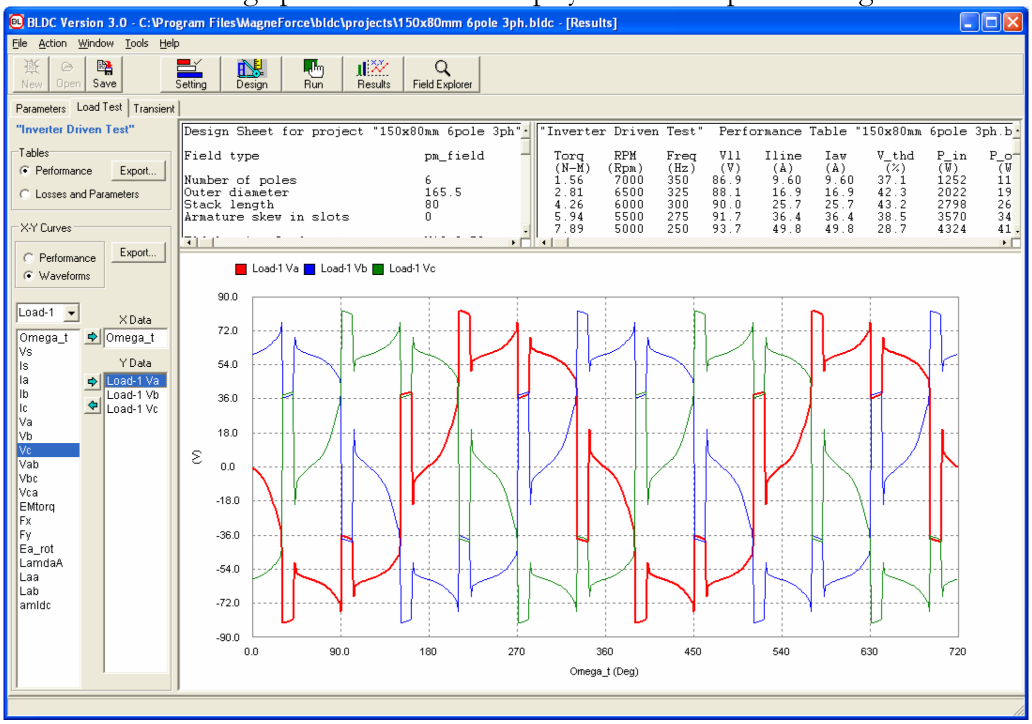


In the example above we have displayed Speed (RPM) vs. Output Power (P_out) and Efficiency (Effic). An export data file of this graph is available by selecting Export.

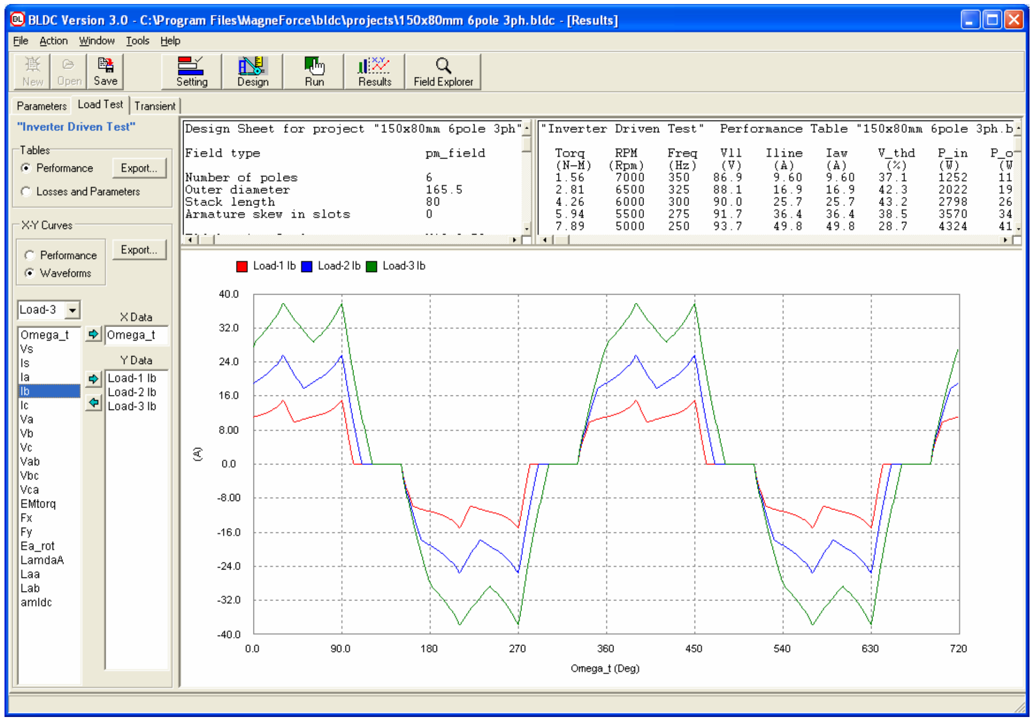


RPM	P_out	Effic
(Rpm)	(W)	(PU)
7.00000e+03	1.14600e+03	9.16000e-01
6.50000e+03	1.91000e+03	9.45000e-01
6.00000e+03	2.67700e+03	9.56000e-01
5.50000e+03	3.42100e+03	9.58000e-01
5.00000e+03	4.13100e+03	9.55000e-01

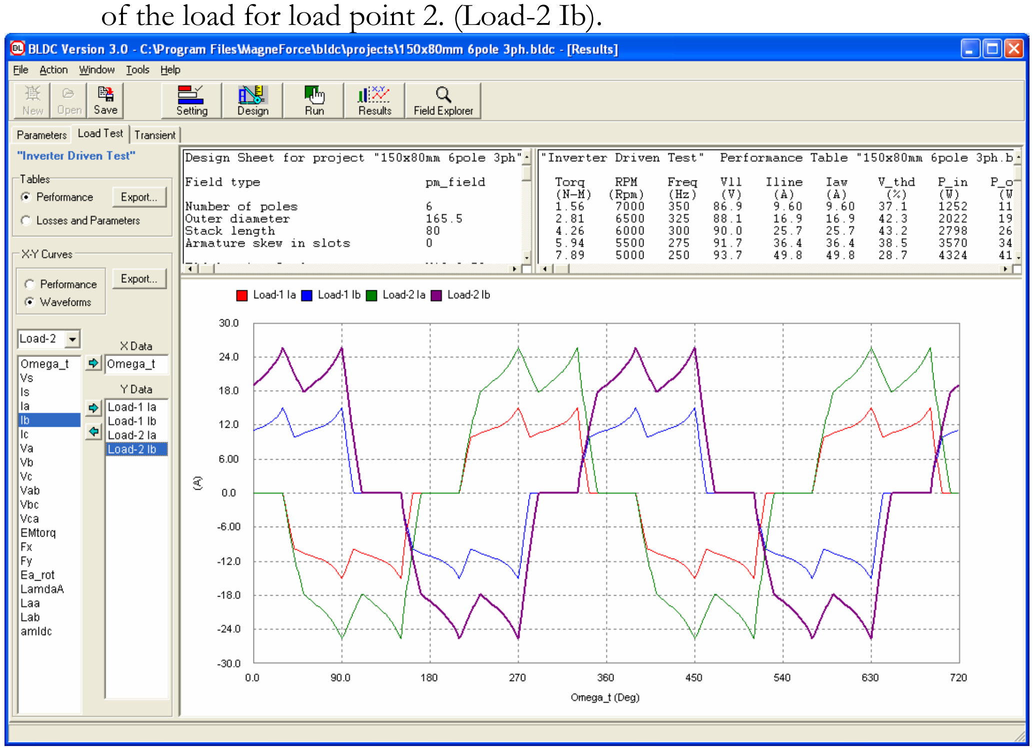
Selecting **Waveforms** will allow you to graph these machine parameters versus time. In the graph below we have displayed the three phase voltages.



Often times you will want to see the same parameter graphed for different load points. This can be accomplished by selecting a load point from the drop down list, selecting the desired parameter, selecting another load point and then selecting the desired parameter again. We have done this below for phase current Ib for three successive load points.



When viewing multiple data sets simultaneously any particular data set can be emphasized by clicking upon it in the Y Data column. In the picture below notice the enhanced nature of the curve for the current in phase B of the load for load point 2. (Load-2 Ib).



As you might expect, the tabular values, as well as the Fourier Coefficients, for all graphs are available through the Export button.

- - Notepad

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Omega_t (Deg)	Load-1 Ia (A)	Load-1 Ib (A)	Load-2 Ia (A)	Load-2 Ib (A)
0.00000e+00	1.00429e-04	1.10909e+01	1.29166e-04	1.90374e+01
1.00000e+00	2.21832e-04	1.11486e+01	2.42674e-04	1.91804e+01
2.00000e+00	3.44691e-04	1.12066e+01	3.57431e-04	1.93238e+01
3.00000e+00	4.69775e-04	1.12654e+01	4.74259e-04	1.94678e+01
4.00000e+00	6.06507e-04	1.13253e+01	6.01848e-04	1.96128e+01
5.00000e+00	7.28007e-04	1.13866e+01	7.15186e-04	1.97590e+01
6.00000e+00	8.68608e-04	1.14495e+01	8.46276e-04	1.99068e+01
7.00000e+00	1.01395e-03	1.15144e+01	9.81645e-04	2.00566e+01
8.00000e+00	1.16786e-03	1.15816e+01	1.12498e-03	2.02086e+01
9.00000e+00	1.33243e-03	1.16516e+01	1.27819e-03	2.03634e+01
1.00000e+01	1.50971e-03	1.17247e+01	1.44312e-03	2.05212e+01
1.10000e+01	1.70190e-03	1.18014e+01	1.62184e-03	2.06825e+01
1.20000e+01	1.91117e-03	1.18821e+01	1.81640e-03	2.08479e+01
1.30000e+01	2.13973e-03	1.19674e+01	2.02883e-03	2.10178e+01
1.40000e+01	2.38977e-03	1.20579e+01	2.26113e-03	2.11929e+01
1.50000e+01	2.66315e-03	1.21543e+01	2.51509e-03	2.13738e+01
1.60000e+01	2.96157e-03	1.22572e+01	2.79225e-03	2.15612e+01
1.70000e+01	3.28634e-03	1.23675e+01	3.09381e-03	2.17560e+01
1.80000e+01	3.63831e-03	1.24861e+01	3.42063e-03	2.19590e+01
1.90000e+01	4.01797e-03	1.26137e+01	3.77305e-03	2.21711e+01
2.00000e+01	4.42507e-03	1.27515e+01	4.15090e-03	2.23933e+01
2.10000e+01	4.85895e-03	1.29003e+01	4.55358e-03	2.26266e+01
2.20000e+01	5.31832e-03	1.30614e+01	4.97985e-03	2.28720e+01
2.30000e+01	5.80120e-03	1.32356e+01	5.42788e-03	2.31305e+01
2.40000e+01	6.30517e-03	1.34241e+01	5.89544e-03	2.34033e+01

- - Notepad

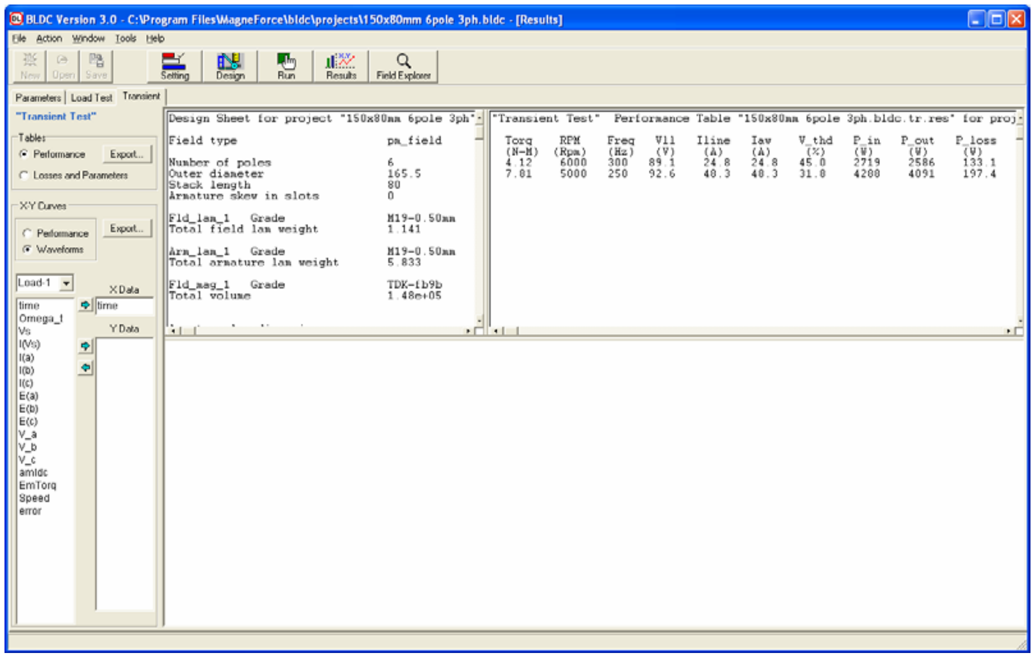
File Edit Format View Help

Fourier Coefficents for "Load-1 Ia":

n	A_n	phi_n
0	-9.58897e-05	0.00000e+00
1	1.30863e+01	1.42047e+00
2	8.75019e-04	8.66475e-01
3	8.69952e-05	1.31477e+00
4	8.30966e-04	1.51127e+00
5	2.51983e+00	-2.61197e+00
6	1.07696e-04	-5.65344e-01
7	2.08342e+00	-2.08402e+00
8	7.91809e-04	-2.94983e+00
9	7.32832e-05	-2.62324e+00
10	7.15540e-04	-2.35464e+00
11	1.07737e+00	-1.55676e-01
12	7.33753e-05	1.69507e+00
13	9.32769e-01	5.66315e-01
14	6.06820e-04	-5.04201e-01
15	5.93954e-05	-2.99813e-01
16	5.31446e-04	7.39462e-02
17	5.05118e-01	2.39786e+00
18	5.78520e-05	-2.31955e+00
19	4.27761e-01	-3.10091e+00
20	3.80646e-04	1.94338e+00
21	4.26675e-05	2.06338e+00

TRANSIENT TAB

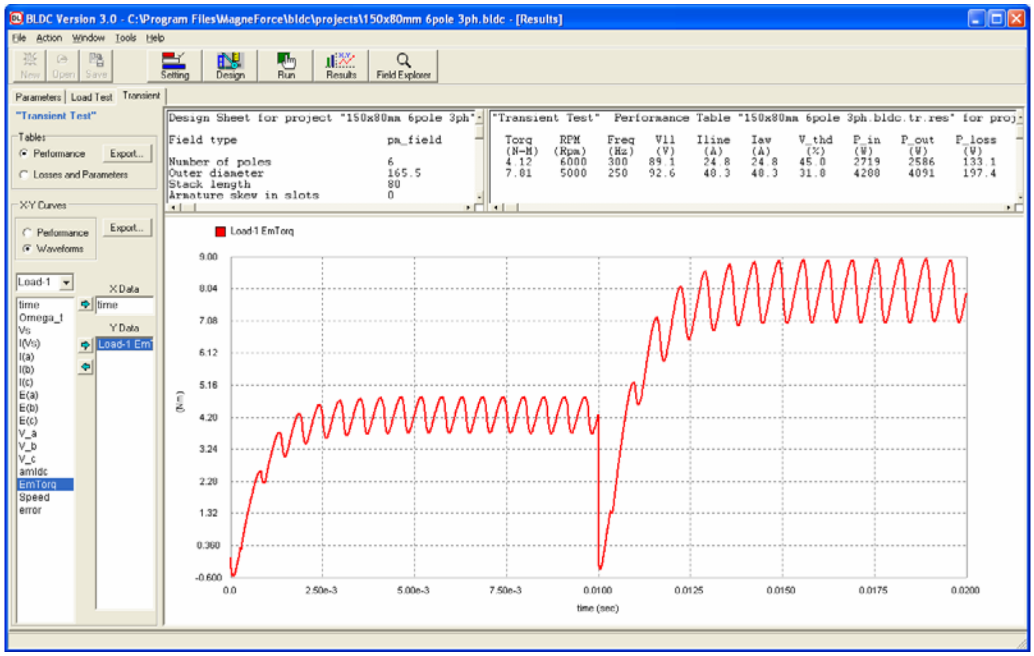
The Transient Tab is used to study machine parameters during a mechanical or electrical transient. The layout of this Tab is similar but not exact to the previous tabs on this panel.



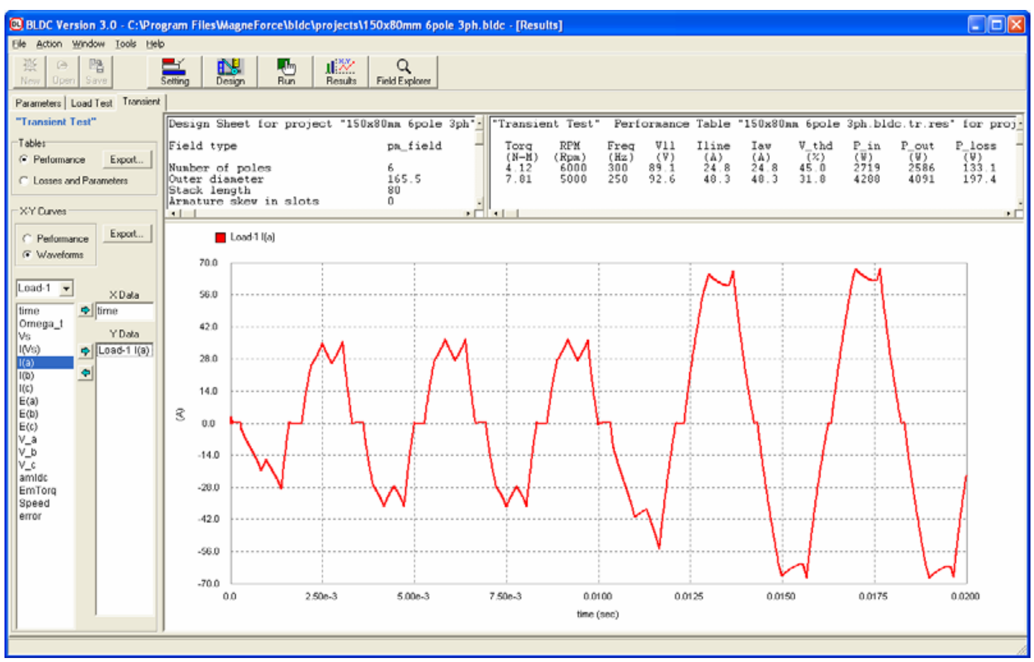
The Transient tab differs from the Parameters and Load Test Tabs in that it contains only Waveform data. Since this tab is used to calculate the machine's response to a transient and is not normally used to view the steady state response the Performance and Loss Separation data sets are not calculated.

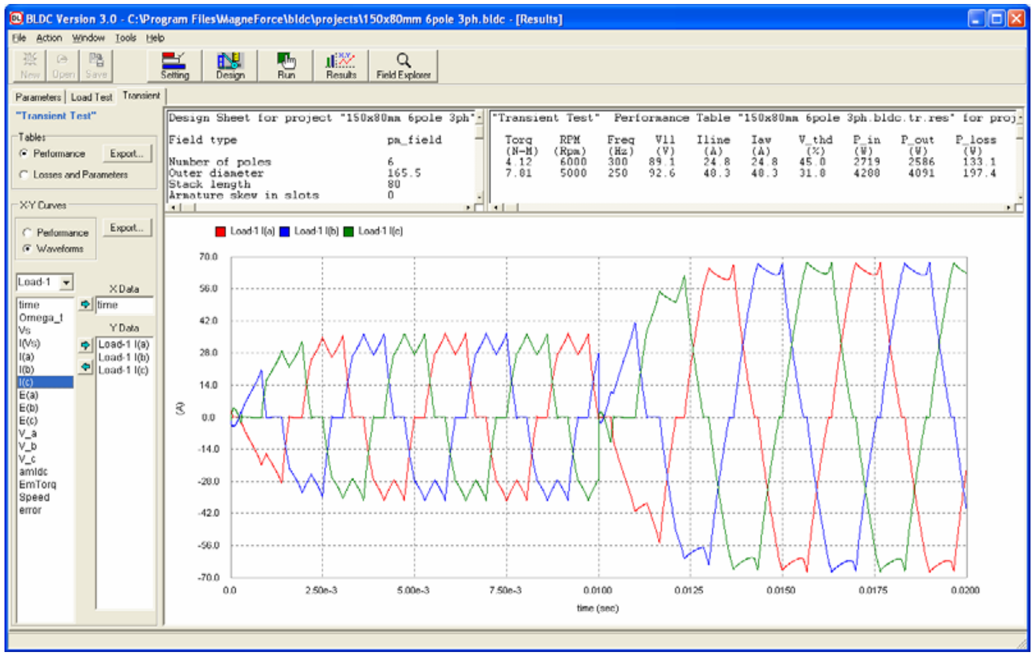
The waveform data that is available includes machine currents, EMF's, and electromagnetic torque as well as any current or voltage sources placed in the drive circuit on the design panel. Additionally, the x-axis of this result panel can be selected to display either Omega t in degrees or Time in seconds.

The figures below all apply to a machine which undergoes a change in speed from 6000 rpm to 5000 rpm. Notice the response from one steady state condition to another. Please note that the beginning of these plots display a numerical transient because the exact starting condition can never be known prior to running the simulation.

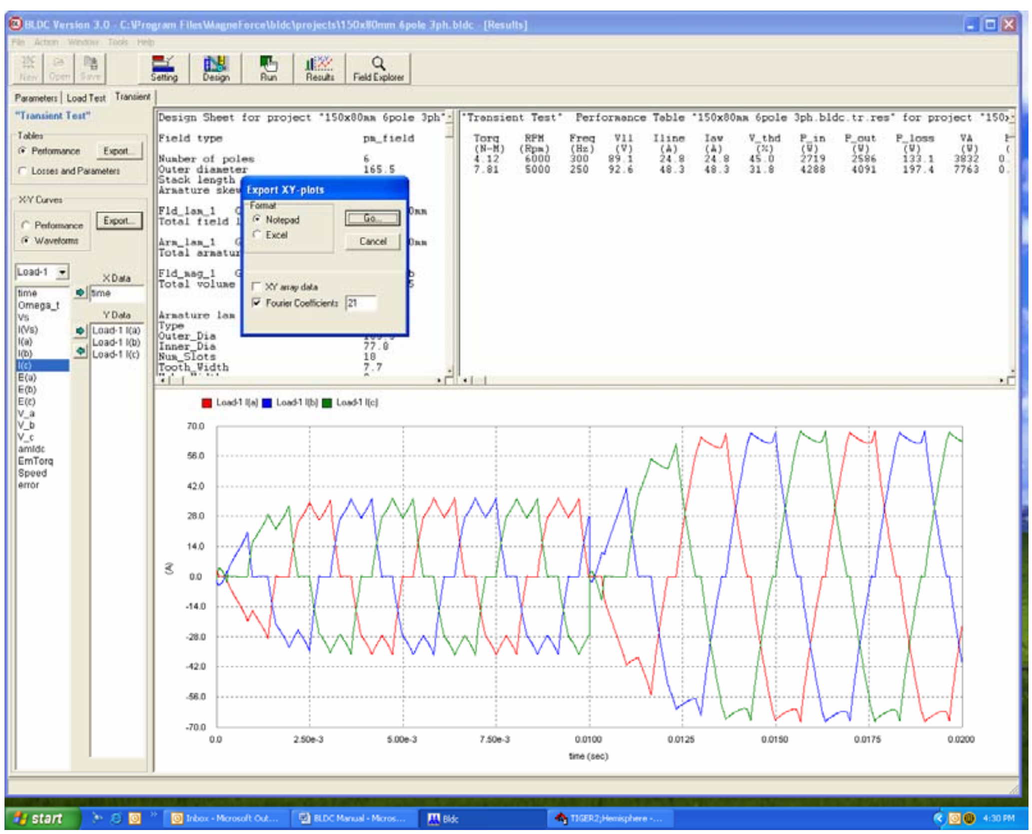


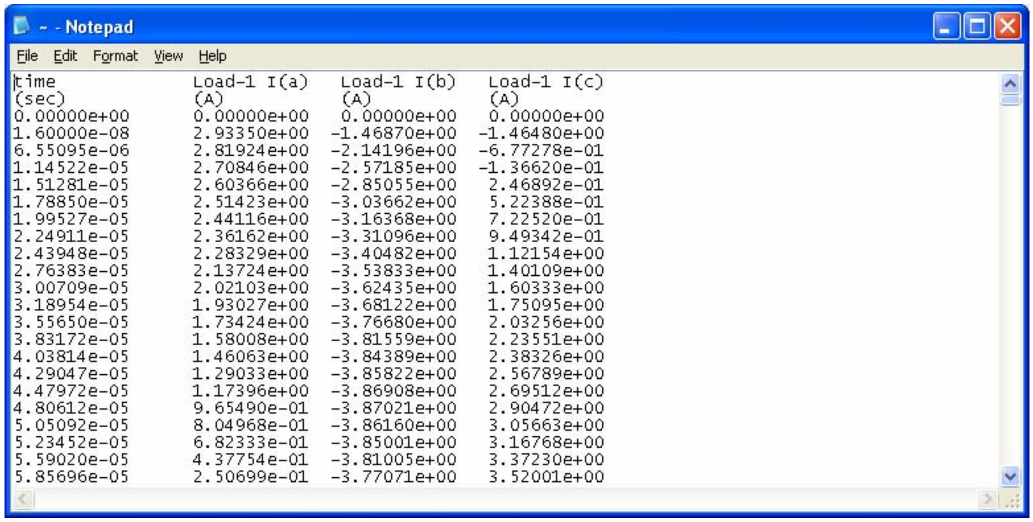
The above figure displays the electromagnetic torque response from the above speed change, while the figure below displays the phase A current during the same event.





The above figure displays the 3-phase machine currents before during and after the rotational speed change. All of these parameters' xy coordinate data are available for export into Notepad or Excel by utilizing the EXPORT button.





time (sec)	Load-1 I(a) (A)	Load-1 I(b) (A)	Load-1 I(c) (A)
0.00000e+00	0.00000e+00	0.00000e+00	0.00000e+00
1.60000e-08	2.93350e+00	-1.46870e+00	-1.46480e+00
6.55095e-06	2.81924e+00	-2.14196e+00	-6.77278e-01
1.14522e-05	2.70846e+00	-2.57185e+00	-1.36620e-01
1.51281e-05	2.60366e+00	-2.85055e+00	2.46892e-01
1.78850e-05	2.51423e+00	-3.03662e+00	5.22388e-01
1.99527e-05	2.44116e+00	-3.16368e+00	7.22520e-01
2.24911e-05	2.36162e+00	-3.31096e+00	9.49342e-01
2.43948e-05	2.28329e+00	-3.40482e+00	1.12154e+00
2.76383e-05	2.13724e+00	-3.53833e+00	1.40109e+00
3.00709e-05	2.02103e+00	-3.62435e+00	1.60333e+00
3.18954e-05	1.93027e+00	-3.68122e+00	1.75095e+00
3.55650e-05	1.73424e+00	-3.76680e+00	2.03256e+00
3.83172e-05	1.58008e+00	-3.81559e+00	2.23551e+00
4.03814e-05	1.46063e+00	-3.84389e+00	2.38326e+00
4.29047e-05	1.29033e+00	-3.85822e+00	2.56789e+00
4.47972e-05	1.17396e+00	-3.86908e+00	2.69512e+00
4.80612e-05	9.65490e-01	-3.87021e+00	2.90472e+00
5.05092e-05	8.04968e-01	-3.86160e+00	3.05663e+00
5.23452e-05	6.82333e-01	-3.85001e+00	3.16768e+00
5.59020e-05	4.37754e-01	-3.81005e+00	3.37230e+00
5.85696e-05	2.50699e-01	-3.77071e+00	3.52001e+00

Once the parameters have been exported to Excel they can be graphed, saved or used in any manner in which you desire. In the transient solution Fourier coefficients are not available for calculation since the waveforms by their very nature are not sinusoidal or periodic.

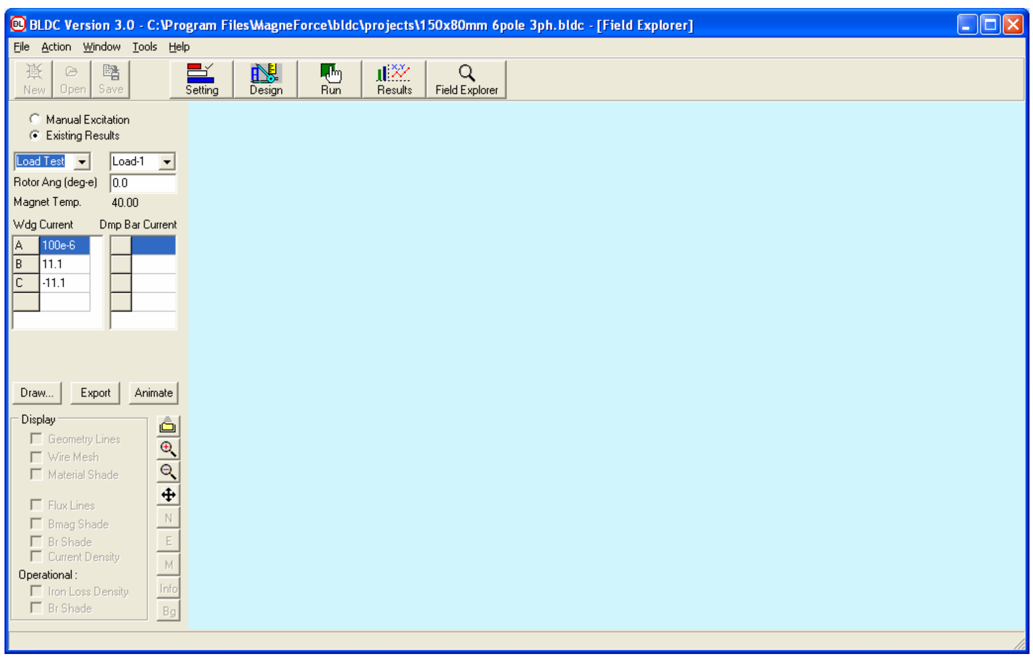
Chapter

9

The Field Explorer Panel

The field explorer panel is used to display the machine geometry, finite element mesh, magnetic field density, current density and iron loss density.

When first selected the Field Explorer Panel will be displayed:



This panel is unique among all panels in that it does not contain any tabs. All results can be displayed from this one screen. The panel is divided into two sections the settings section and the display section. The settings section is to the left and is where you specify the conditions and parameters to be displayed. The display section is the larger of the two sections and is where the cross sectional results are displayed.

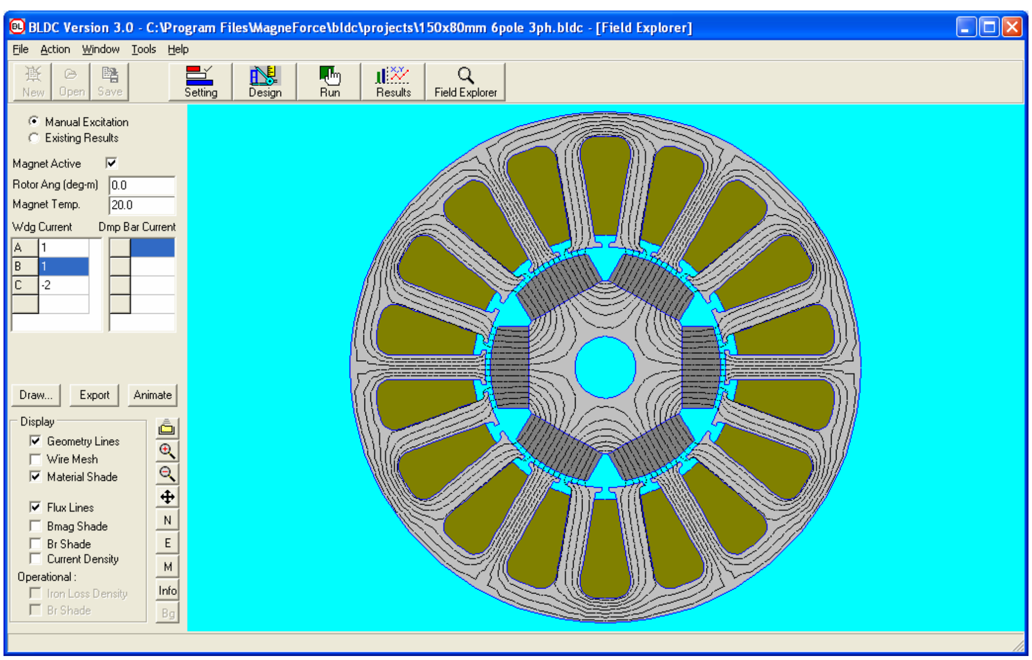
MANUAL EXCITATION

At the top of the settings section is a check box to either select **Manual Excitation** or **Existing Results.** The Manual Excitation selection allows you to enter the machine's excitation manually. If the machine in question has permanent magnets you will be allowed to check or uncheck the **Magnet Active** check box. With this box checked the effects of the machine's permanent magnets will be included and conversely the permanent magnets effects will be ignored if left unchecked.

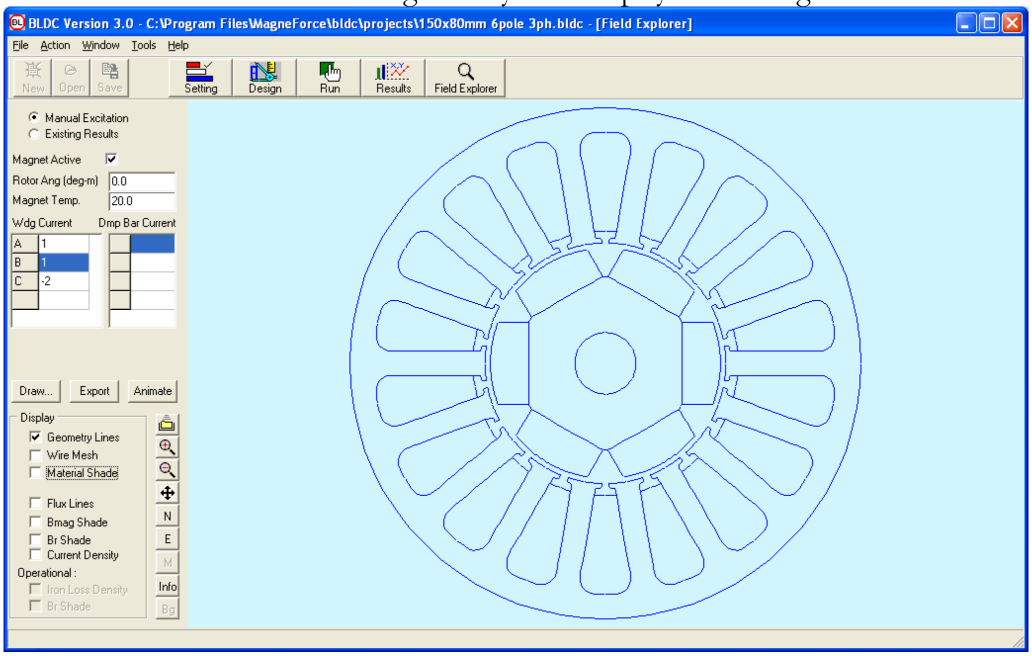
Below this is a **Rotor Angle** field. Enter the rotor angle in degrees for the solution point you are interested in. Below this is a **Magnet Temp** field, which, if the machine is equipped with permanent magnets is the temperature of these magnets in Celsius.

Below these settings are two tables that describe the current in the armature windings and the damper bars, if applicable. Fill these in as appropriate.

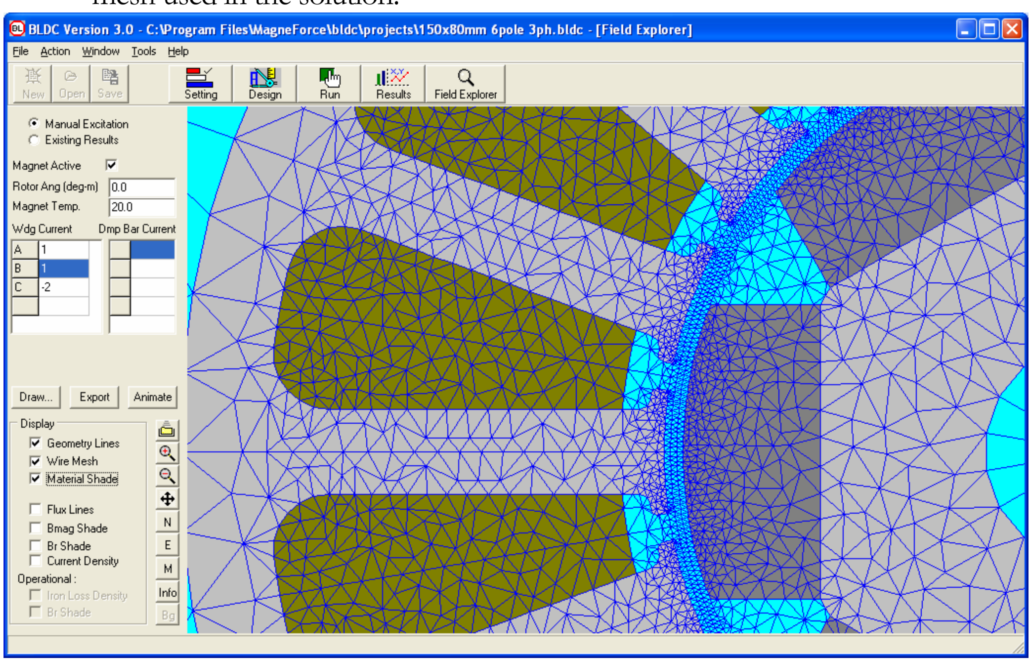
Once these parameters have been completed click the **Draw** button.



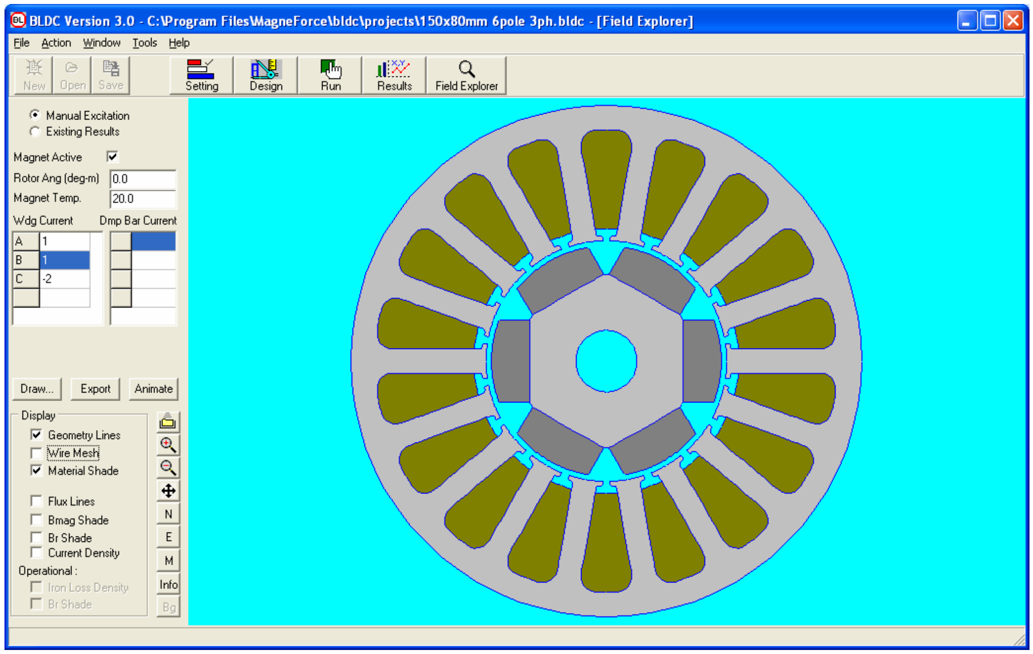
In the box below the draw button you will have several options. The first is **Geometry Lines** which is automatically selected. This check box causes the machine's cross-sectional geometry to be displayed to the right.



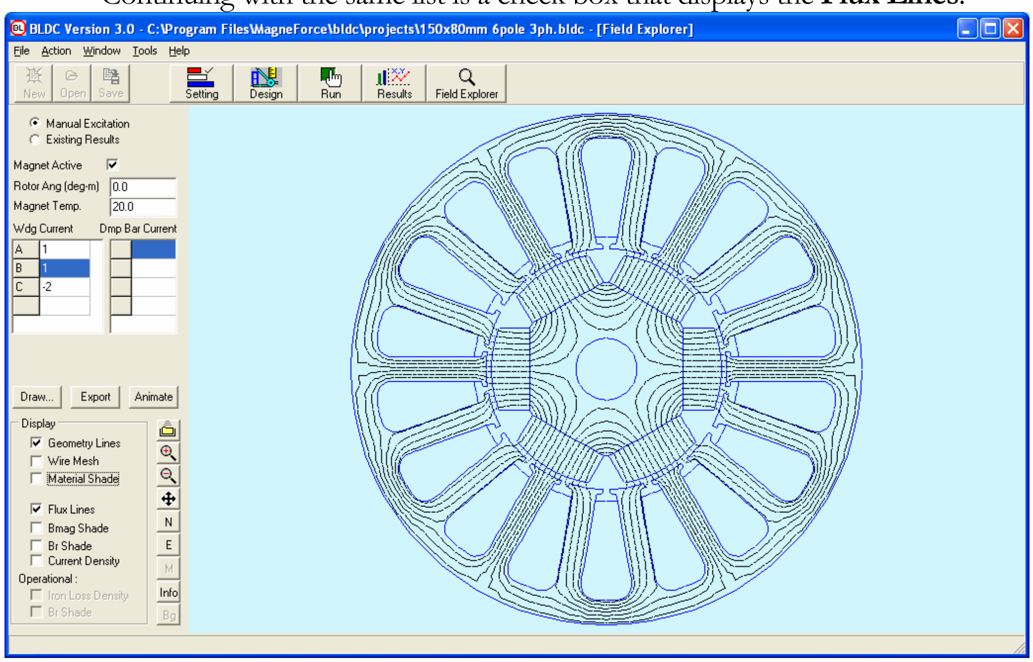
The next option is the **Wire Mesh** check box which displays the finite element mesh used in the solution.



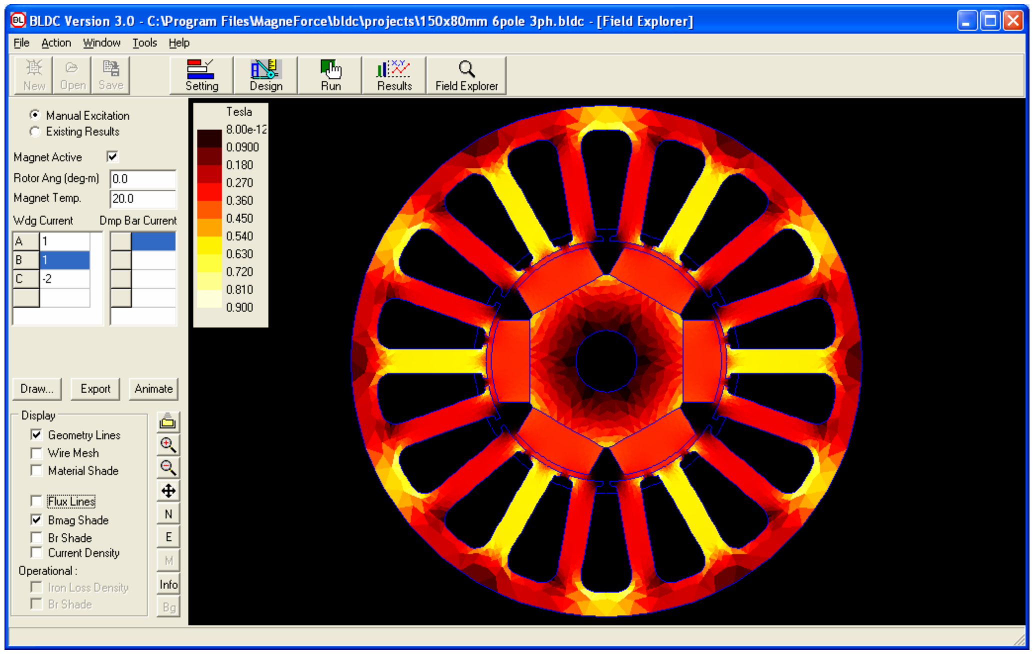
The next option is the **Material Shade** check box which displays the distinct materials in the cross section with different colors.



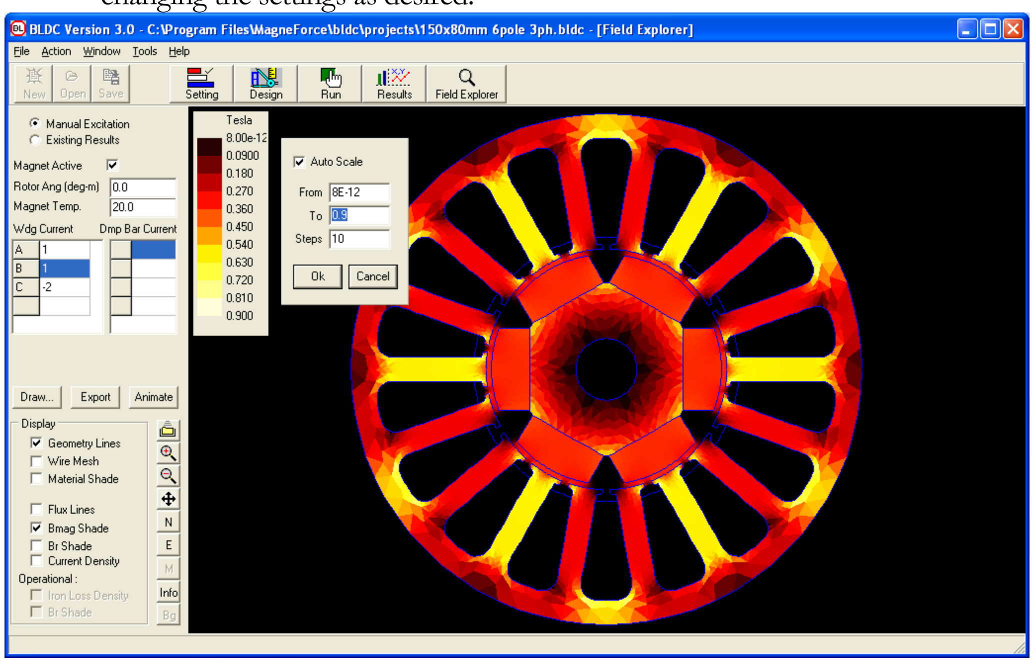
Continuing with the same list is a check box that displays the **Flux Lines**.



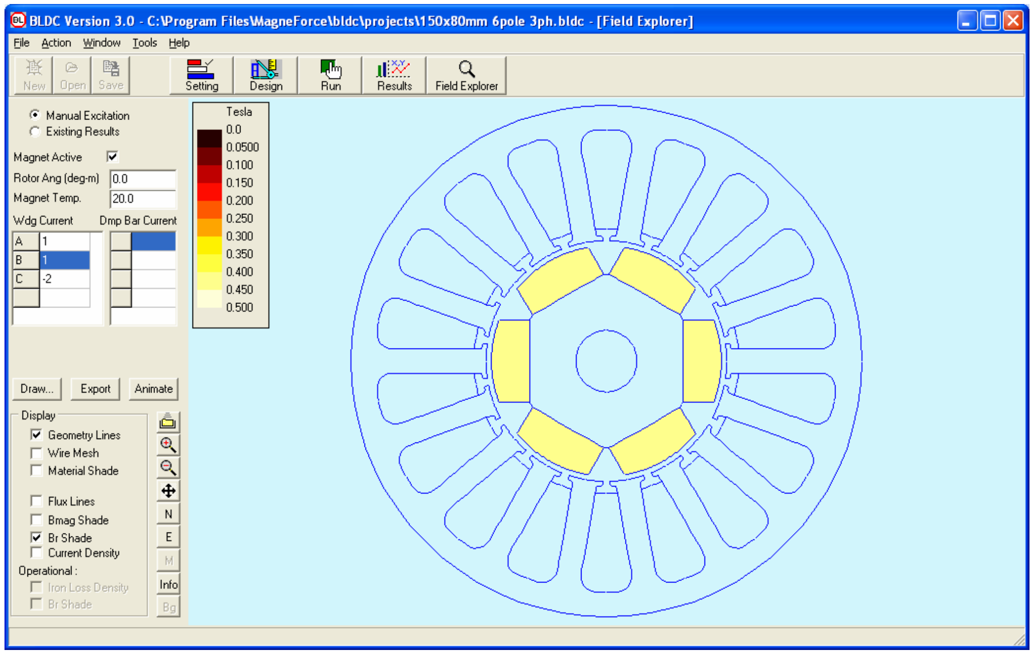
Under the Flux Lines option is the **Bmag Shade** check box that displays the magnetic flux density for this particular solution point along with a legend. The flux density is diplayed in Tesla.



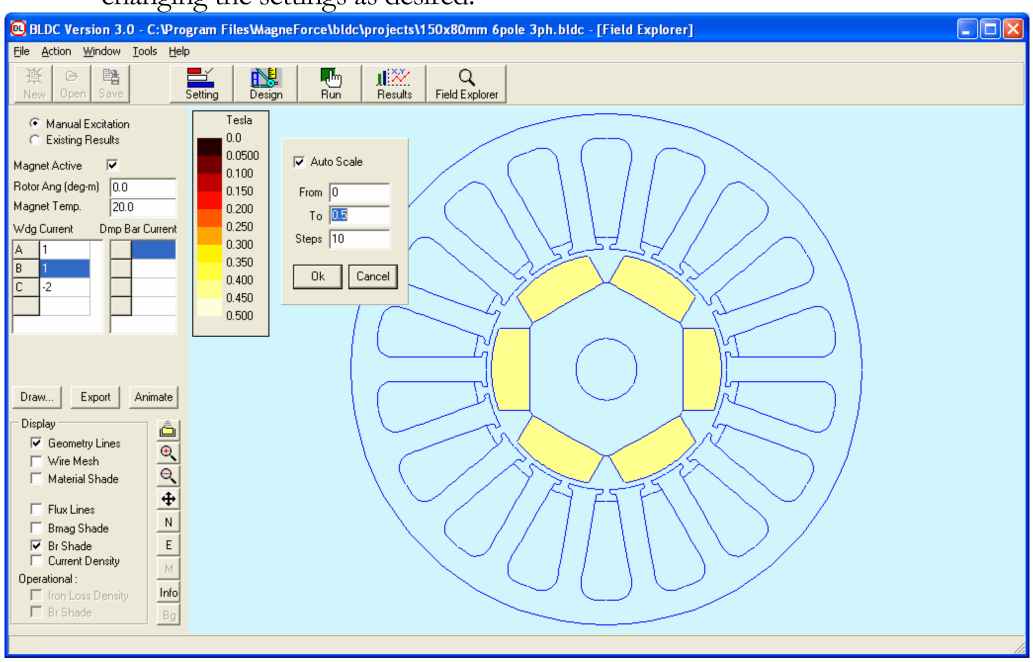
The scale of the flux density can be changed by double clicking the legend and changing the settings as desired.



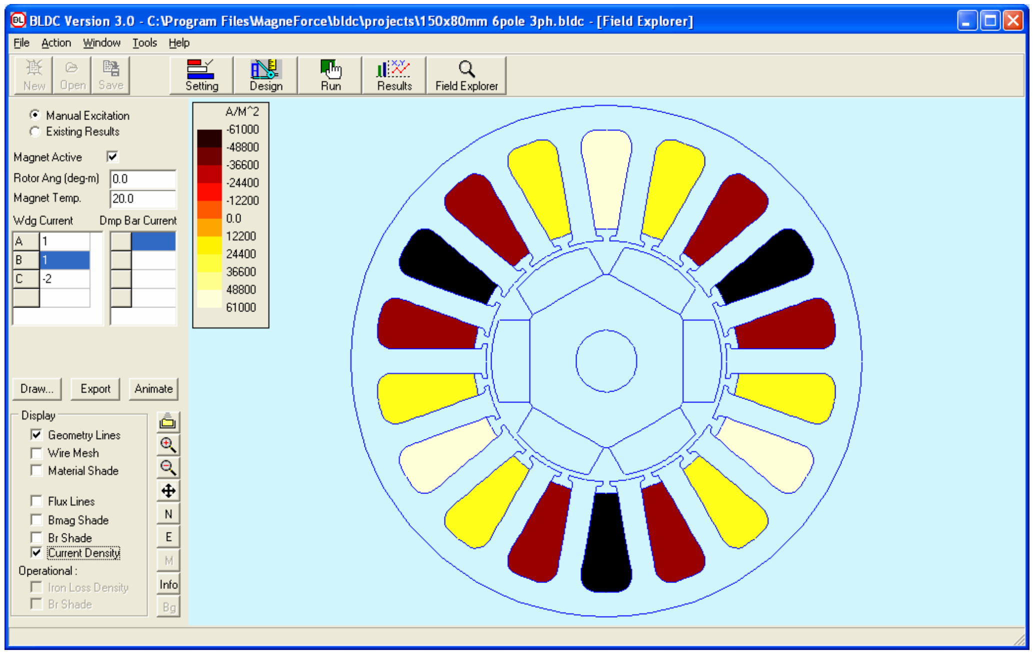
Br Shade is the next displayable parameter and when selected displays the residual flux density in the permanent magnets.



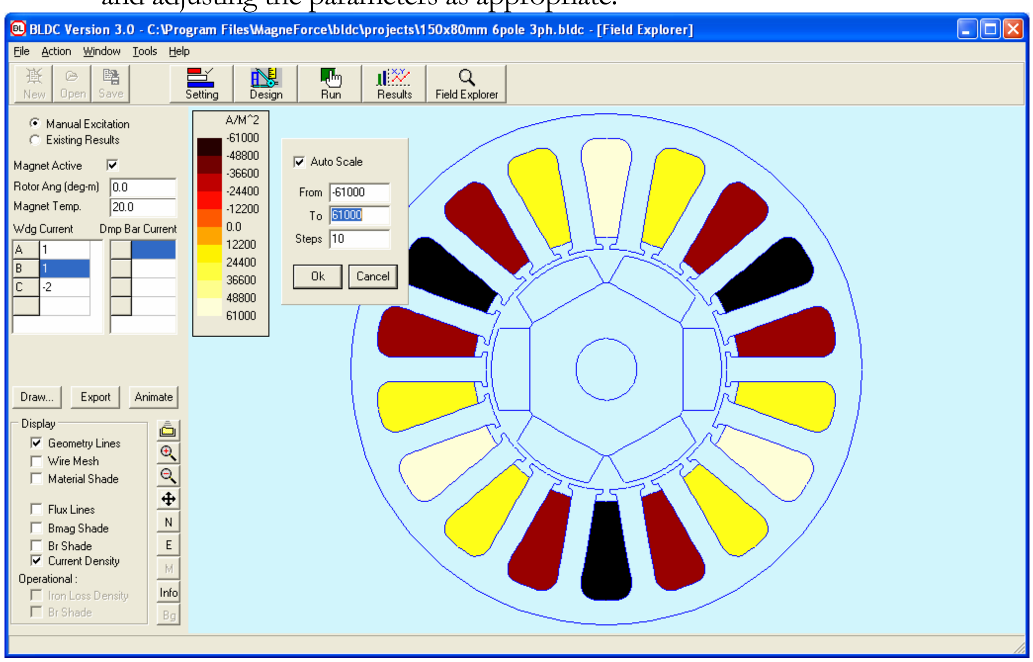
The scale of the flux density can be changed by double clicking the legend and changing the settings as desired.



The final parameter that can be displayed is the **Current Density** which when selected will show the current density in Amps/square meter.

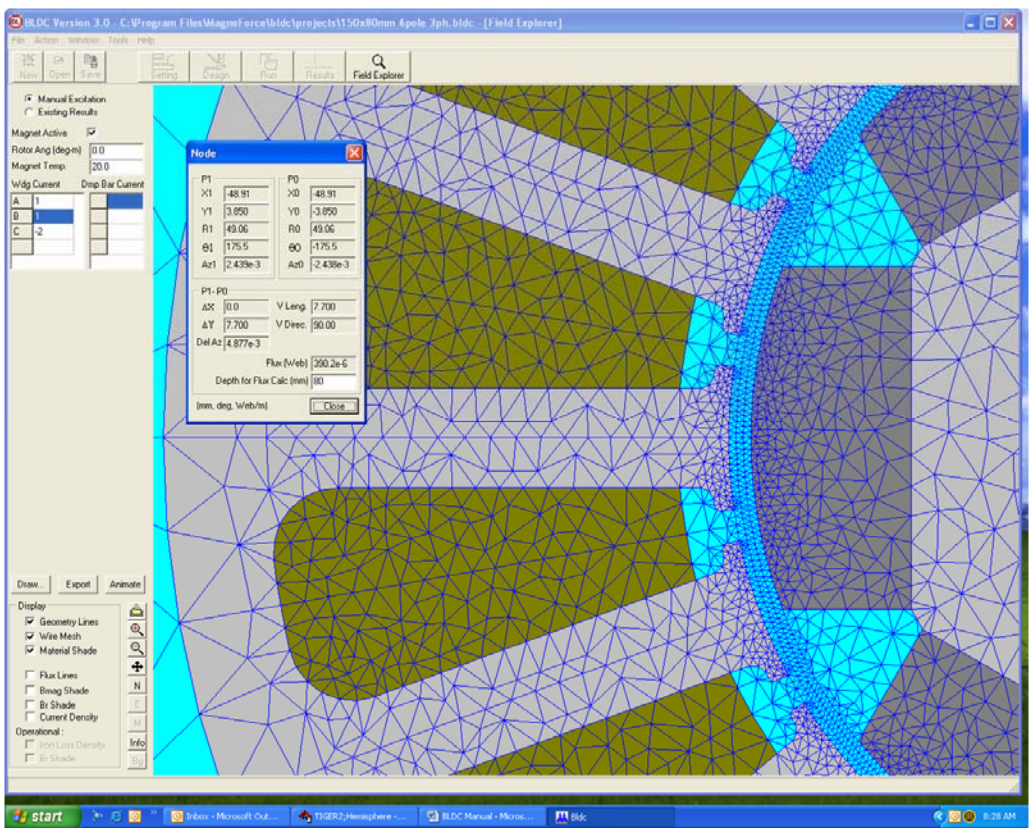


The scale of this parameter can also be adjusted by double clicking the legend and adjusting the parameters as appropriate.

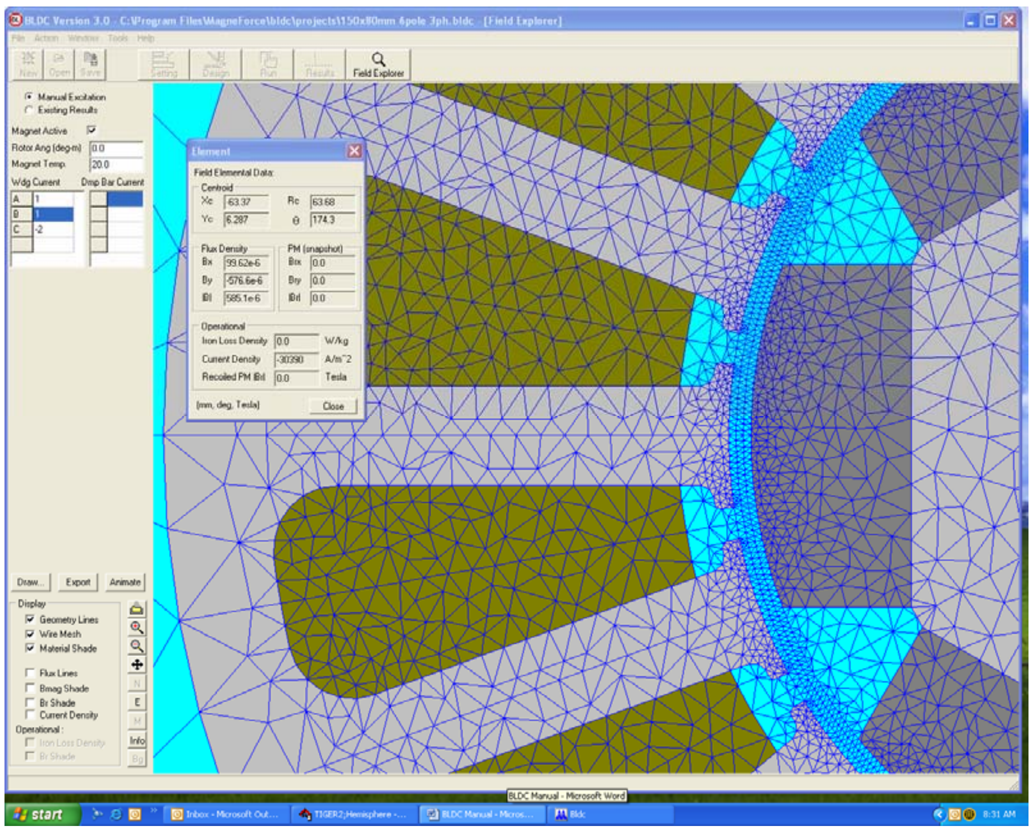


To the right of these check boxes are several sizing and information buttons. To zoom in on the image use the **Plus** button or to zoom out click the **Minus** button, to normalize the image size click the **Normalize** button or to shift the image click the **4-Arrows** button then move your cursor to the drawing area and click and drag the image the desired distance.

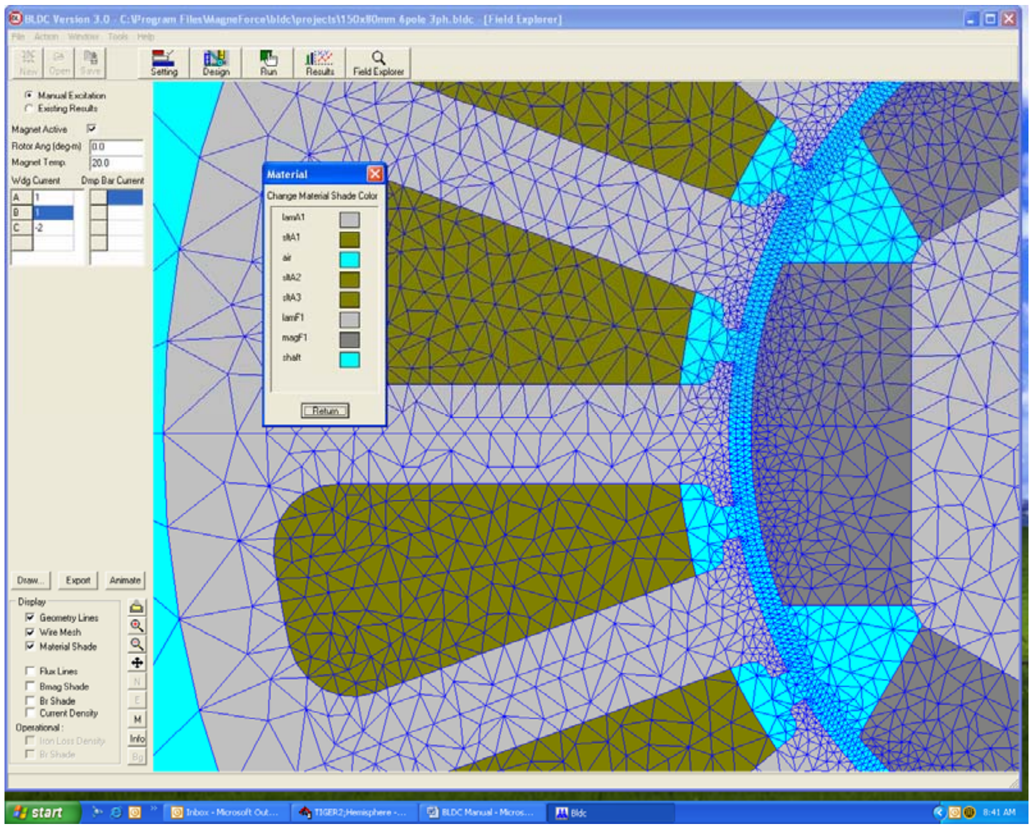
The button labeled **N** is the nodal button which when clicked displays information about the nodes. This button is most often used in conjunction with the wire mesh check box. An information box will be displayed that contains parameter information about two different nodes labeled **P0** and **P1** and you will be allowed to click on the wire mesh. The most recently clicked node is P1 and the node clicked just prior is P0. In the nodal information box the x, y, r, Theta and Az parameters are listed. Just below this is the differential information between P0 and P1. Listed here are Delta x, Delta y, Delta Az as well as the Vector Length and Direction. Below this is a Flux calculator that will give you the flux in Webers for a given depth between P1 and P0.



Under the nodal information button is a button labeled **E**, which is the elemental information button. This button is similar to the nodal information button, except that it displays information about the currently selected finite element. The centroid of the currently selected element is displayed both in x, y and r, theta coordinates. Below this is a listing of the elements flux density, including the Br values if the element lies within a permanent magnet. Under the Operational heading are several parameters that will be displayed if applicable to the selected element. For example if an element lies within a steel lamination it will have a corresponding **Iron Loss Density** value.

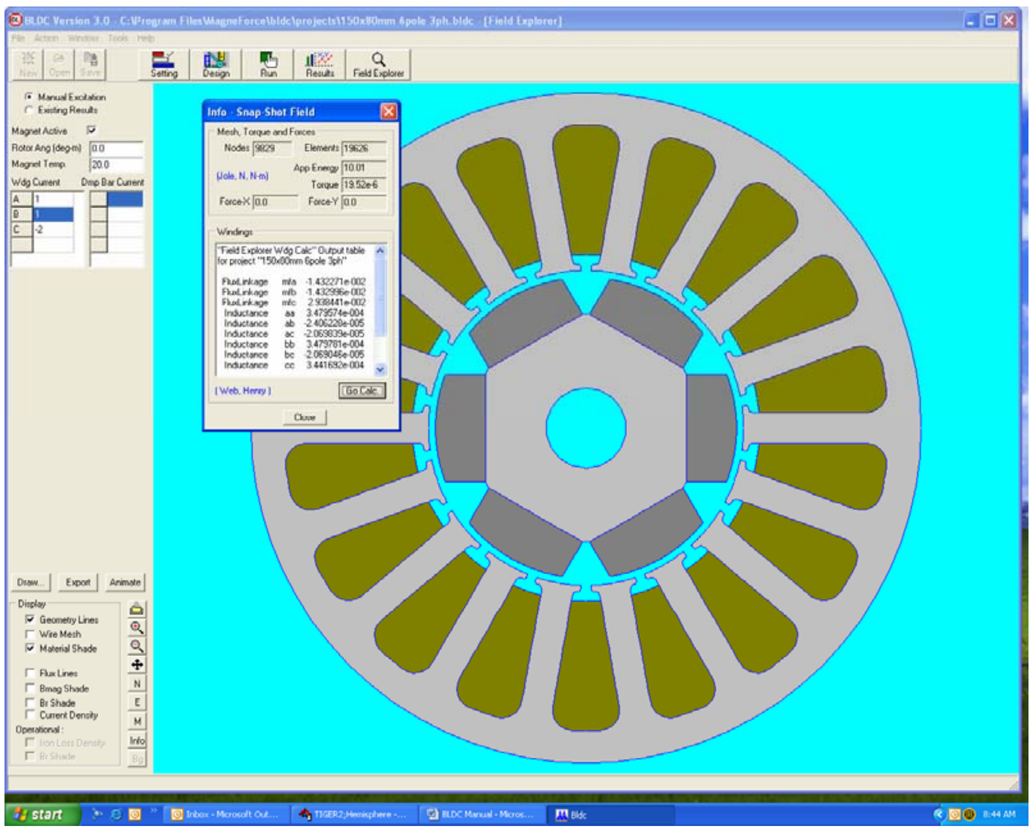


When the Material Shade checkbox is active the material button, represented by an **M**, is also activated. Clicking this button will allow you to change the color that each material type is displayed with. Each winding slot is treated as a separate material and as such can be assigned a distinct color, or you may wish to set all slots to the same color.

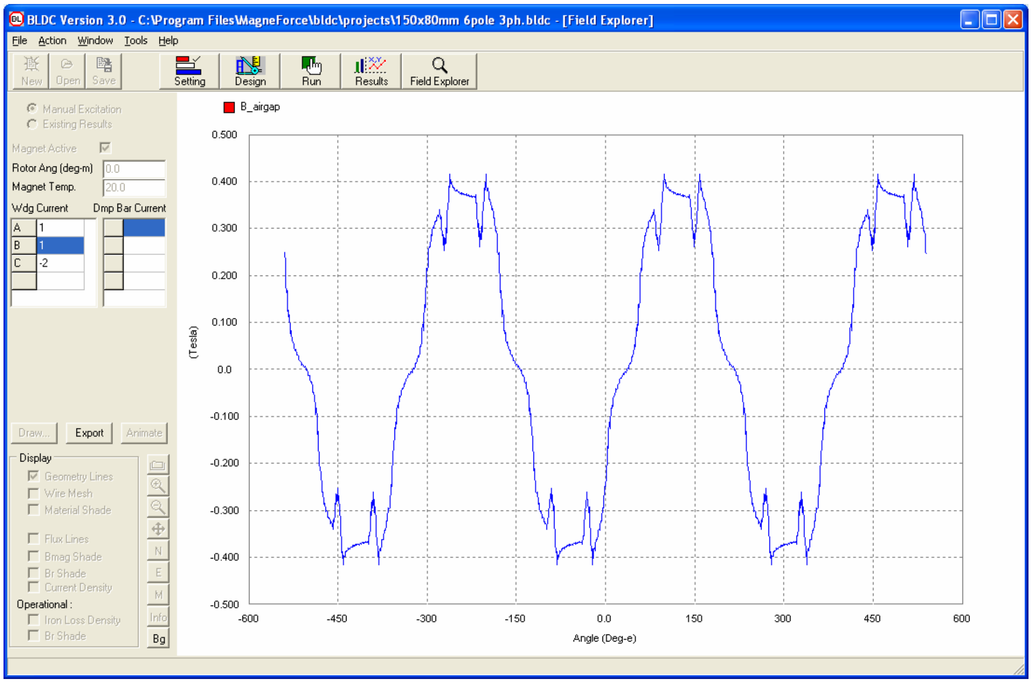


The next informational button is labeled **Info**. When clicked general finite element mesh information such as total number of nodes and elements is displayed. The remainder of the information displayed in this window is specific to the excitation and rotor angle that the machine is currently set to. The parameters displayed are the **Apparent Energy, Torque and the X and Y components of Force.**

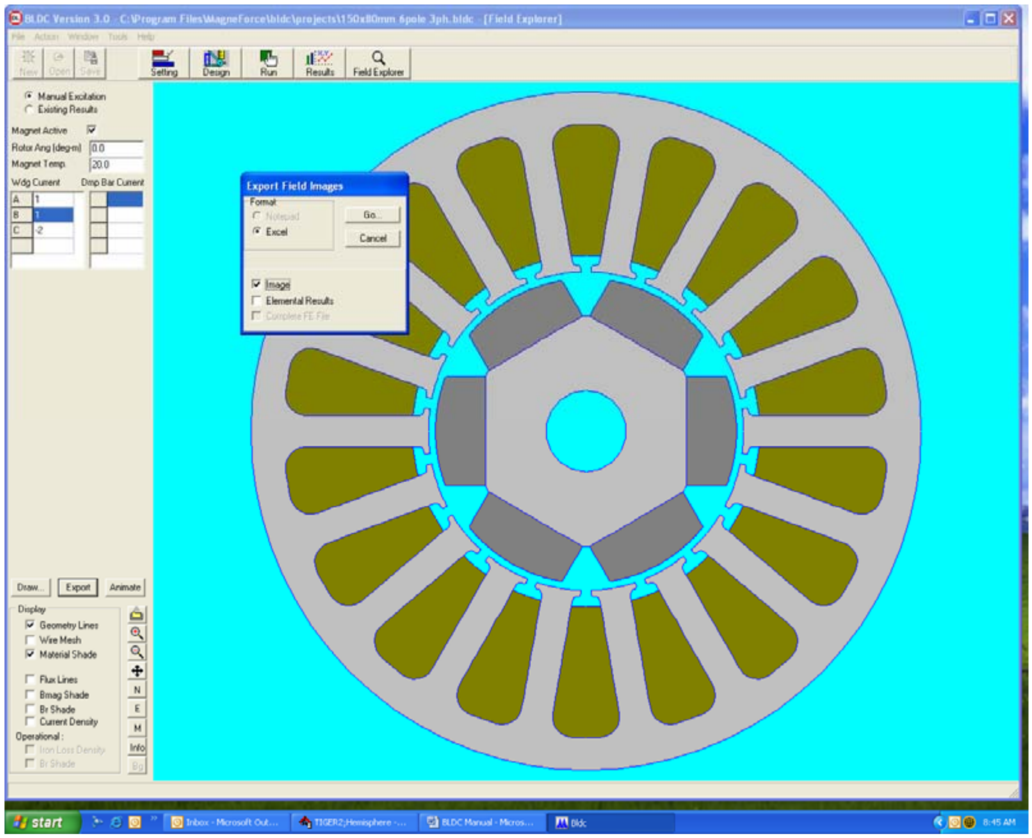
Snapshot winding information is available by clicking the **Go Calc** button in the lower right corner of this window. BLDC will calculate and display the instantaneous **Winding Flux Linkages, Inductances and Rotational EMF Coefficients**. When finished click the Close button.

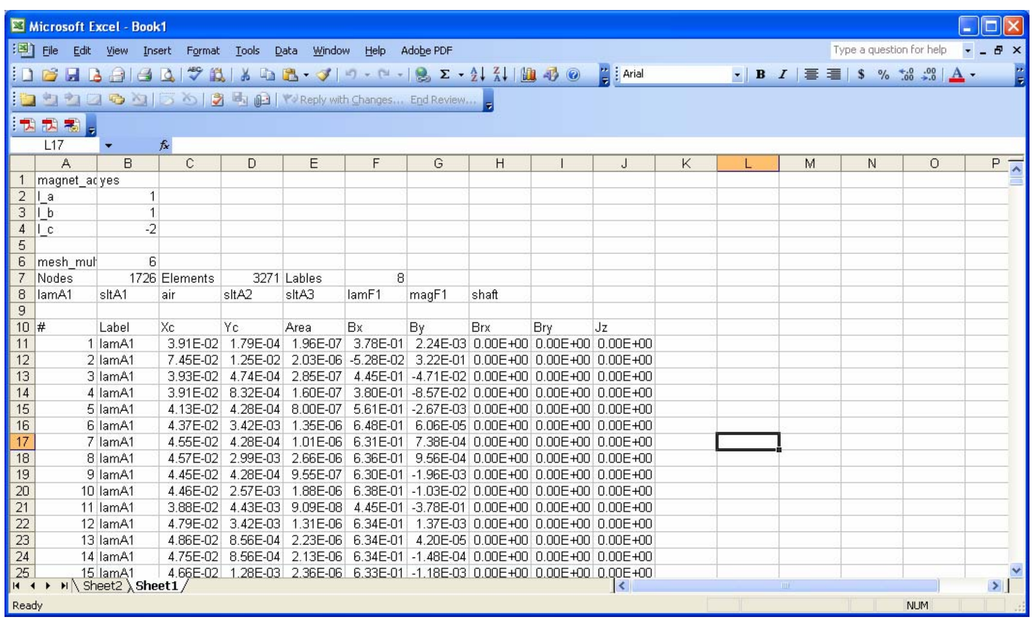


The final informational button is labeled **Bg**. Clicking this button will produce a plot of the mid-gap flux density in Webers vs Electrical Degrees, at the current rotor angle and excitation level. Click the **Bg** button again to return to the normal display.



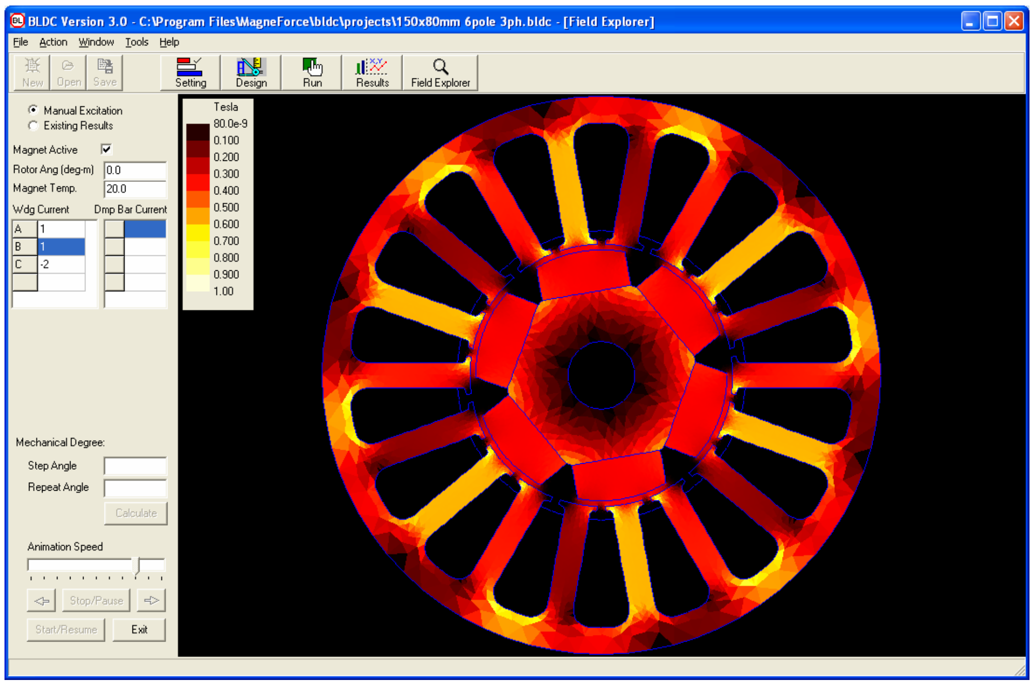
The **Export** button allows a number of parameters to be exported in Microsoft Excel format. The parameters that can be exported are the machine's cross sectional image and the complete finite element file.





	A	B	C	D	E	F	G	H	I	J
1	magnet_ac	yes								
2	I_a	1								
3	I_b	1								
4	I_c	-2								
5										
6	mesh_mul	6								
7	Nodes	1726	Elements	3271	Lables	8				
8	lamA1	sltA1	air	sltA2	sltA3	lamF1	magF1	shaft		
9										
10	#	Label	Xc	Yc	Area	Bx	By	Brx	Bry	Jz
11	1	lamA1	3.91E-02	1.79E-04	1.96E-07	3.78E-01	2.24E-03	0.00E+00	0.00E+00	0.00E+00
12	2	lamA1	7.45E-02	1.25E-02	2.03E-06	-5.28E-02	3.22E-01	0.00E+00	0.00E+00	0.00E+00
13	3	lamA1	3.93E-02	4.74E-04	2.85E-07	4.45E-01	-4.71E-02	0.00E+00	0.00E+00	0.00E+00
14	4	lamA1	3.91E-02	8.32E-04	1.60E-07	3.80E-01	-8.57E-02	0.00E+00	0.00E+00	0.00E+00
15	5	lamA1	4.13E-02	4.28E-04	8.00E-07	5.61E-01	-2.67E-03	0.00E+00	0.00E+00	0.00E+00
16	6	lamA1	4.37E-02	3.42E-03	1.35E-06	6.48E-01	6.06E-05	0.00E+00	0.00E+00	0.00E+00
17	7	lamA1	4.55E-02	4.28E-04	1.01E-06	6.31E-01	7.38E-04	0.00E+00	0.00E+00	0.00E+00
18	8	lamA1	4.57E-02	2.99E-03	2.66E-06	6.36E-01	9.56E-04	0.00E+00	0.00E+00	0.00E+00
19	9	lamA1	4.45E-02	4.28E-04	9.55E-07	6.30E-01	-1.96E-03	0.00E+00	0.00E+00	0.00E+00
20	10	lamA1	4.46E-02	2.57E-03	1.88E-06	6.38E-01	-1.03E-02	0.00E+00	0.00E+00	0.00E+00
21	11	lamA1	3.88E-02	4.43E-03	9.09E-08	4.45E-01	-3.78E-01	0.00E+00	0.00E+00	0.00E+00
22	12	lamA1	4.79E-02	3.42E-03	1.31E-06	6.34E-01	1.37E-03	0.00E+00	0.00E+00	0.00E+00
23	13	lamA1	4.86E-02	8.56E-04	2.23E-06	6.34E-01	4.20E-05	0.00E+00	0.00E+00	0.00E+00
24	14	lamA1	4.75E-02	8.56E-04	2.13E-06	6.34E-01	-1.48E-04	0.00E+00	0.00E+00	0.00E+00
25	15	lamA1	4.66E-02	1.28E-03	2.36E-06	6.33E-01	-1.18E-03	0.00E+00	0.00E+00	0.00E+00

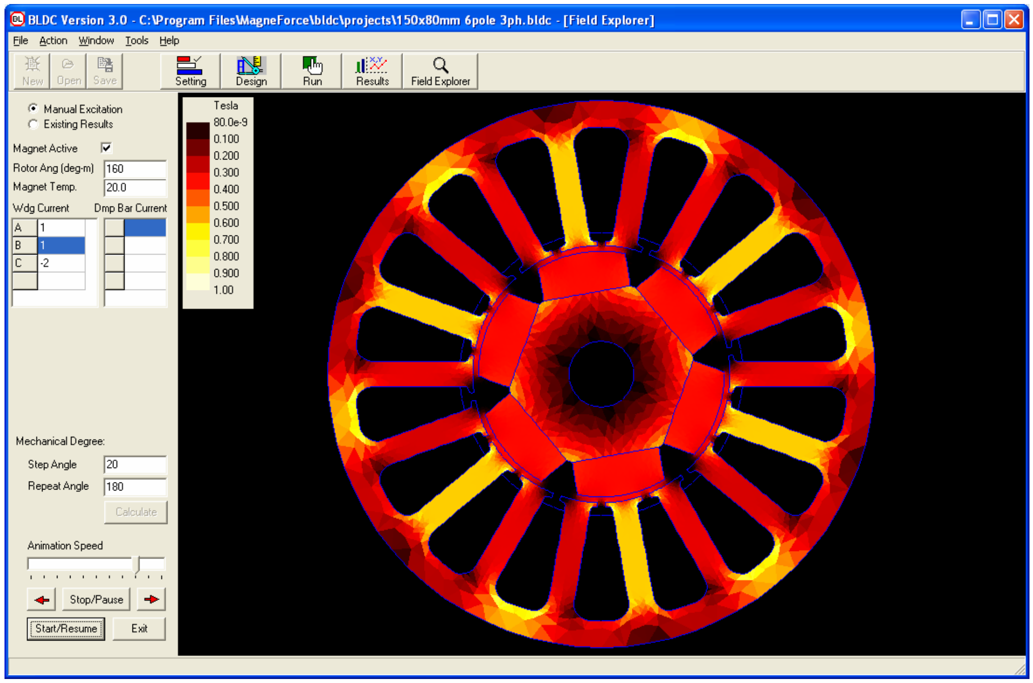
The **Animate** button allows you to see the field parameters in action as the machine would run. BLDC will step through a series of rotor positions and calculate the field parameter, flux density for example, at each position. You will then have the option of displaying these solutions one after another thereby forming an animation of a rotating machine. Clicking the **Animate** button will change the screen as below:



Input the following parameters:

- **Step Angle** is the increment between each rotor position solution point.
- **Repeat Angle** is the total angle that BLDC will calculate to. It will start at zero and calculate up to this point.

Once the two parameters have been entered click the **Calculate** button and BLDC will step through the desired positions calculating the field parameter chosen. Upon completion you will see the screen below:



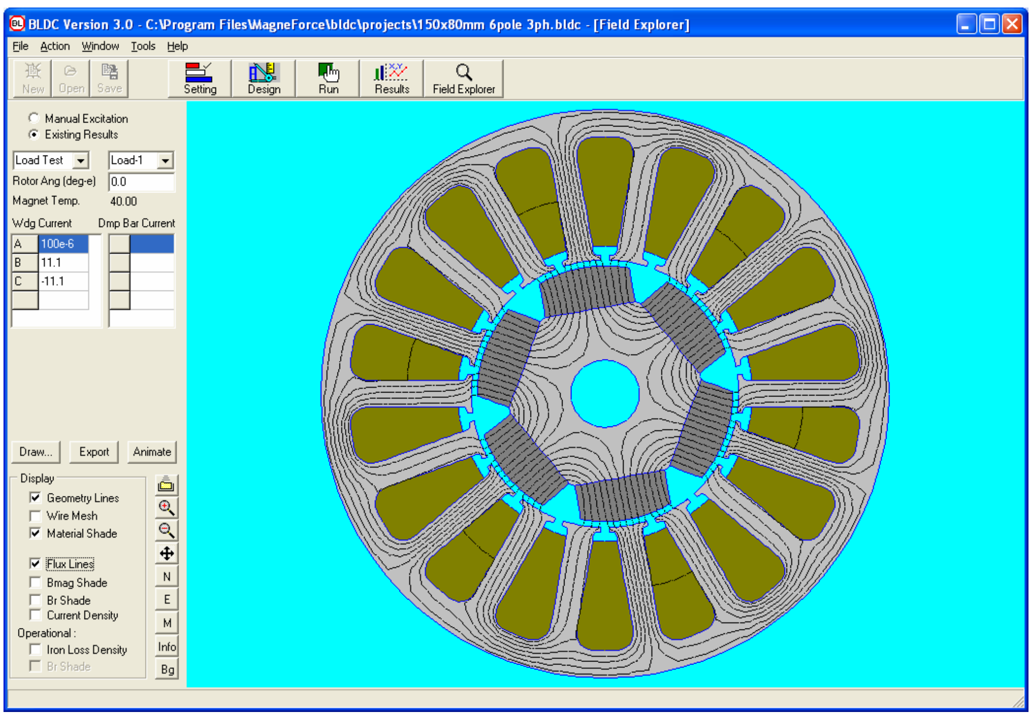
Click the **Start/Resume** button to start and stop the animation being displayed. You may use the **Animation Speed** scroll bar to speed up or slow down the animation. You may also use the **Red Arrows** and the **Pause** button to step through each of the rotor positions manually. When finished viewing the animation click the **Exit** button to return to the normal field explorer display.

EXISTING RESULTS

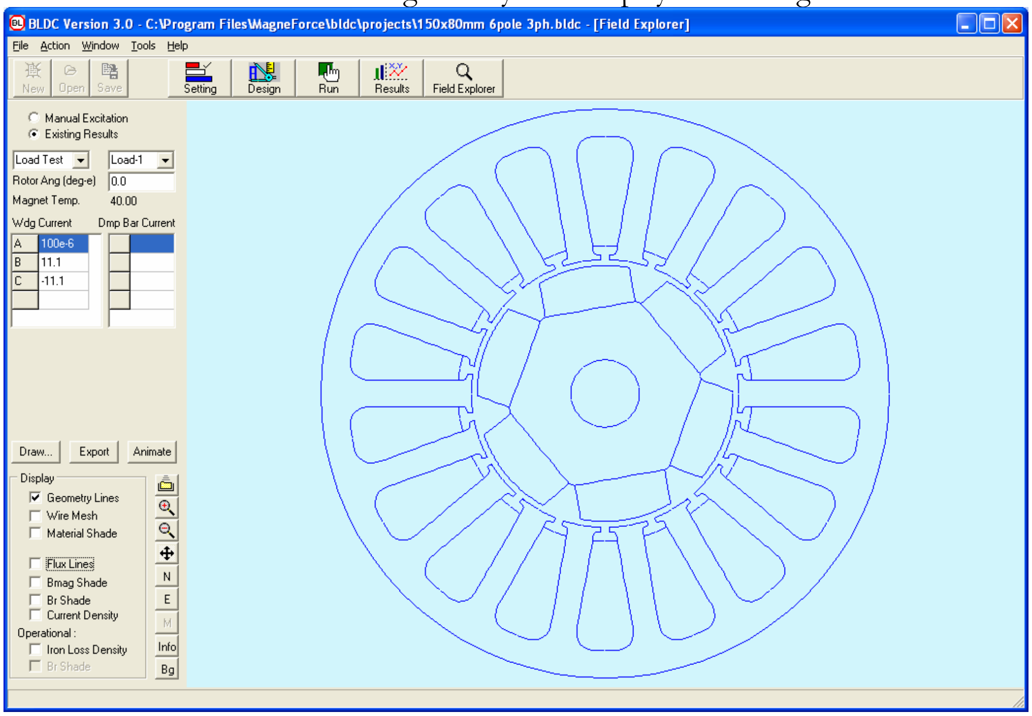
At the top of the settings section click **Existing Results.** Two drop down lists appear. One allowing you to select from the various tests that were selected and performed on the run panel. These test range from parameters to load test to transient. The other drop down list allows you to specify the load point of interest. Next you must select the rotor angle expressed in degrees and enter it in the box labeled **Rotor Ang (deg)**.

Upon completing these fields the program will populate the appropriate values for the following parameters, Magnet Temperature (Magnet Temp), Armature Current (Arm Current) and Damper Bar Current (Dmp Bar Current).

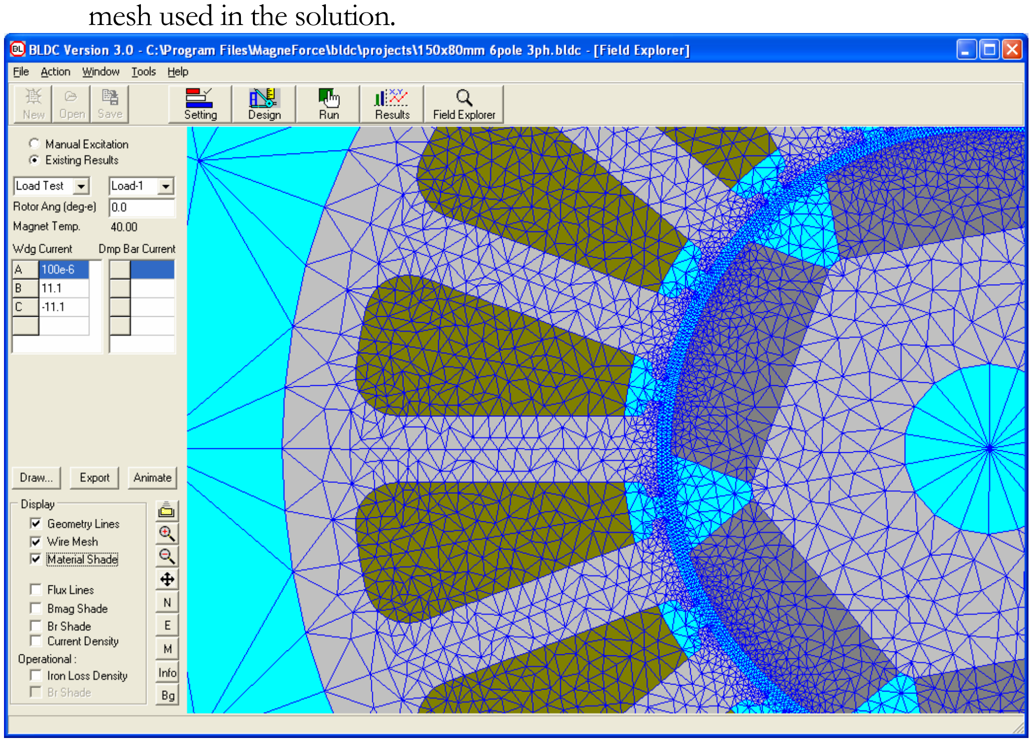
Once these parameters have been completed click the **Draw** button.



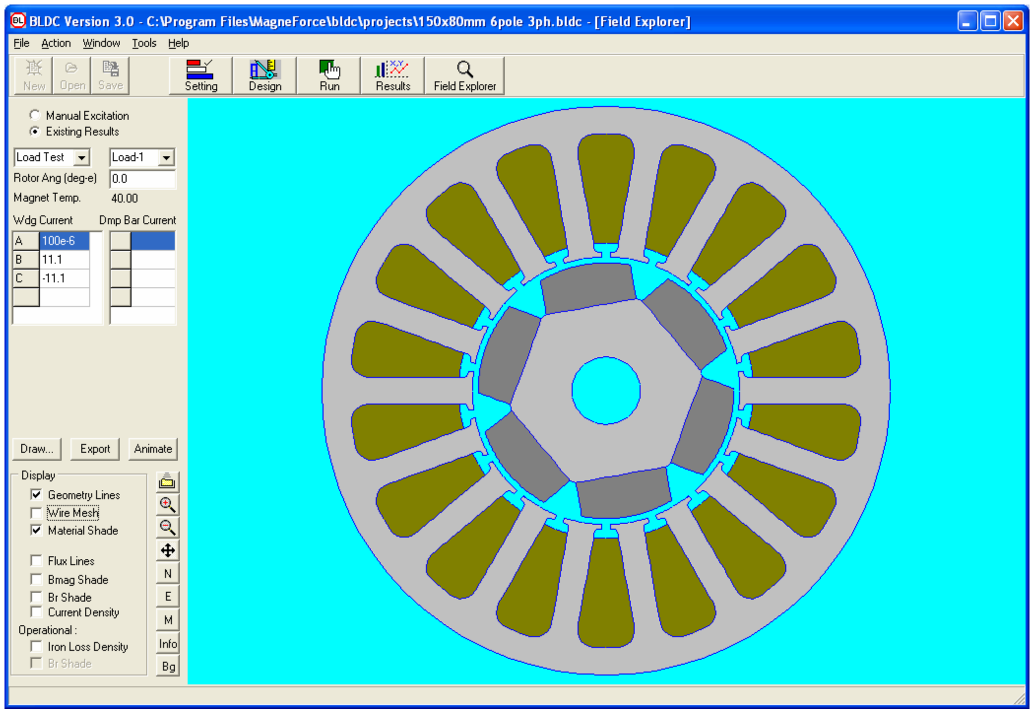
In the box below the draw button you will have several options. The first is **Geometry Lines** which is automatically selected. This check box causes the machine's cross-sectional geometry to be displayed to the right.



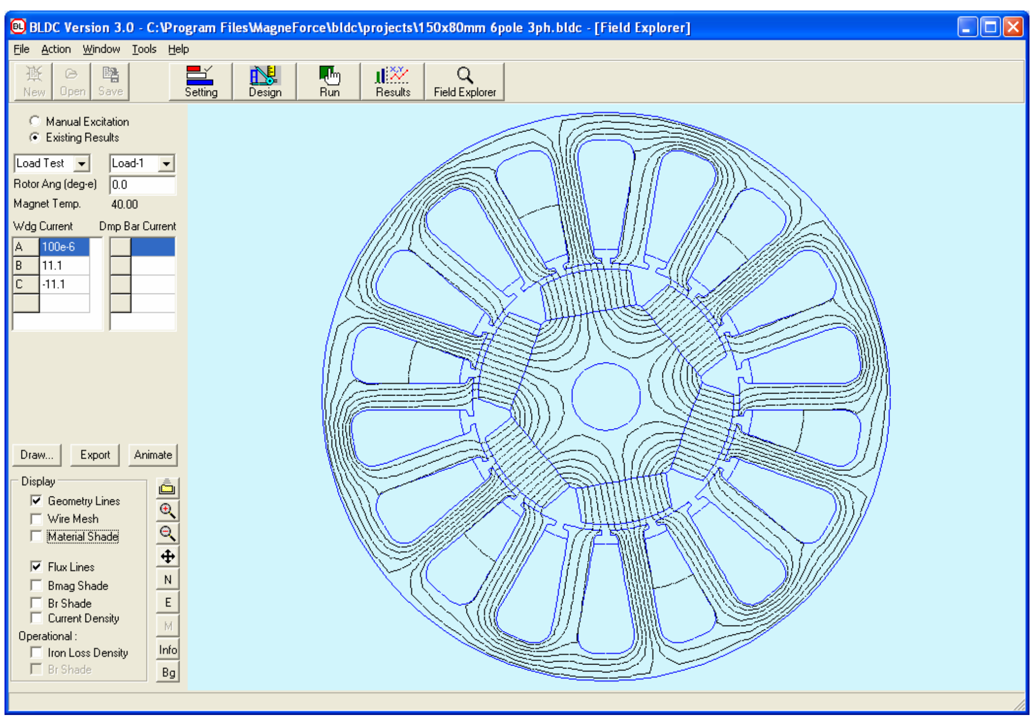
The next option is the **Wire Mesh** check box which displays the finite element mesh used in the solution.



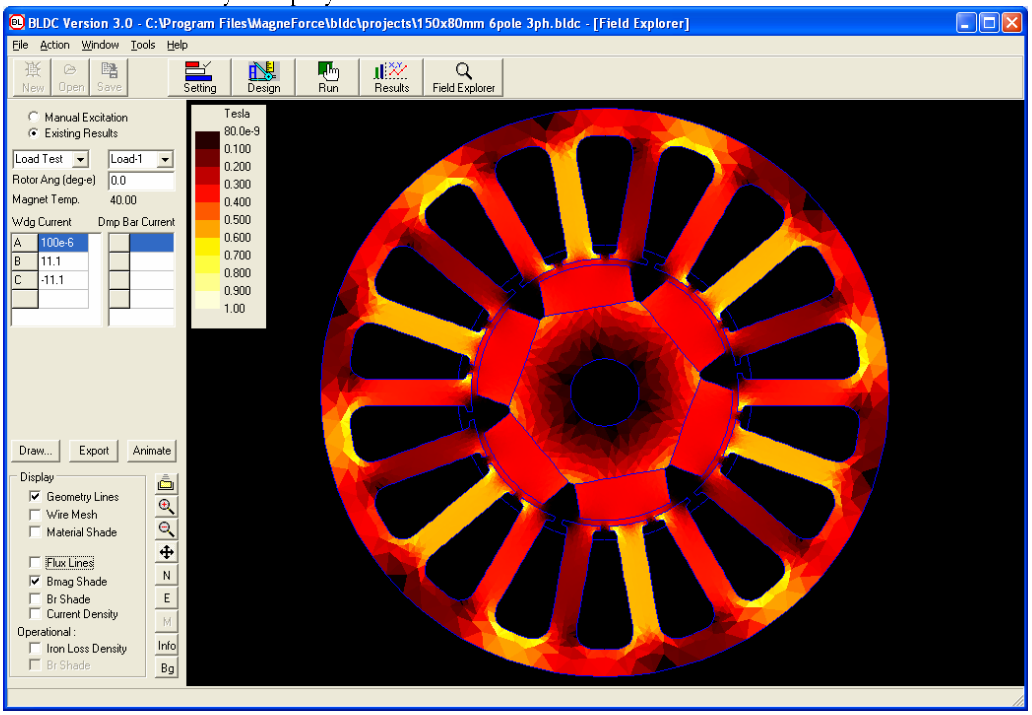
The next option is the **Material Shade** check box which displays the distinct materials in the cross section with different colors.



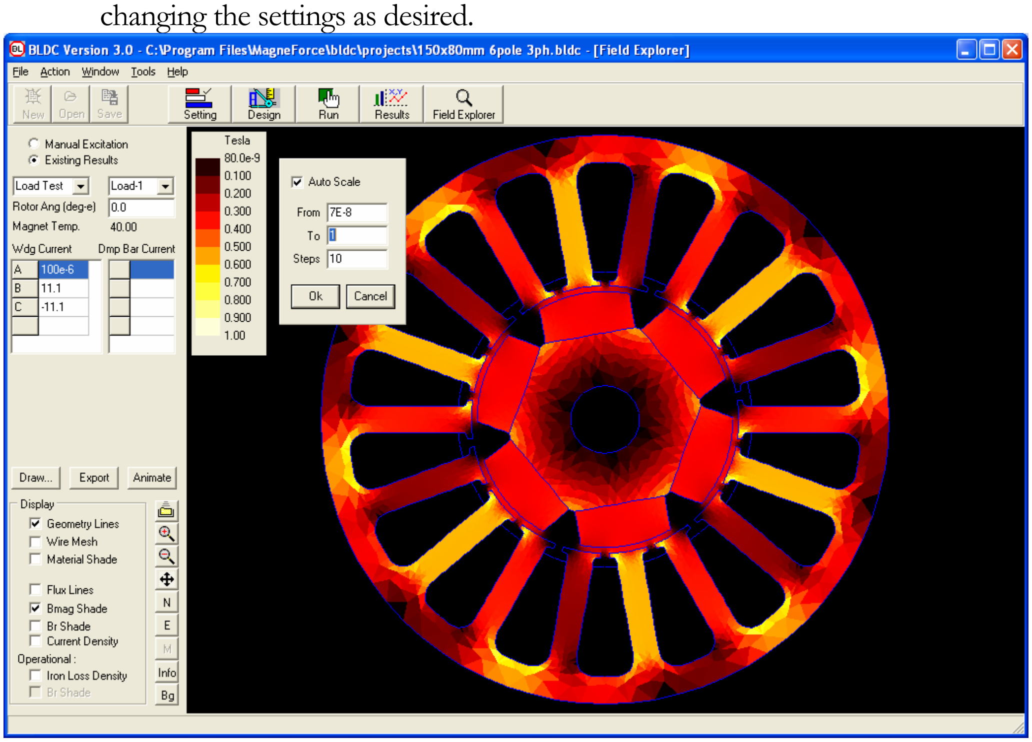
Continuing with the same list is a check box that displays the **Flux Lines**.



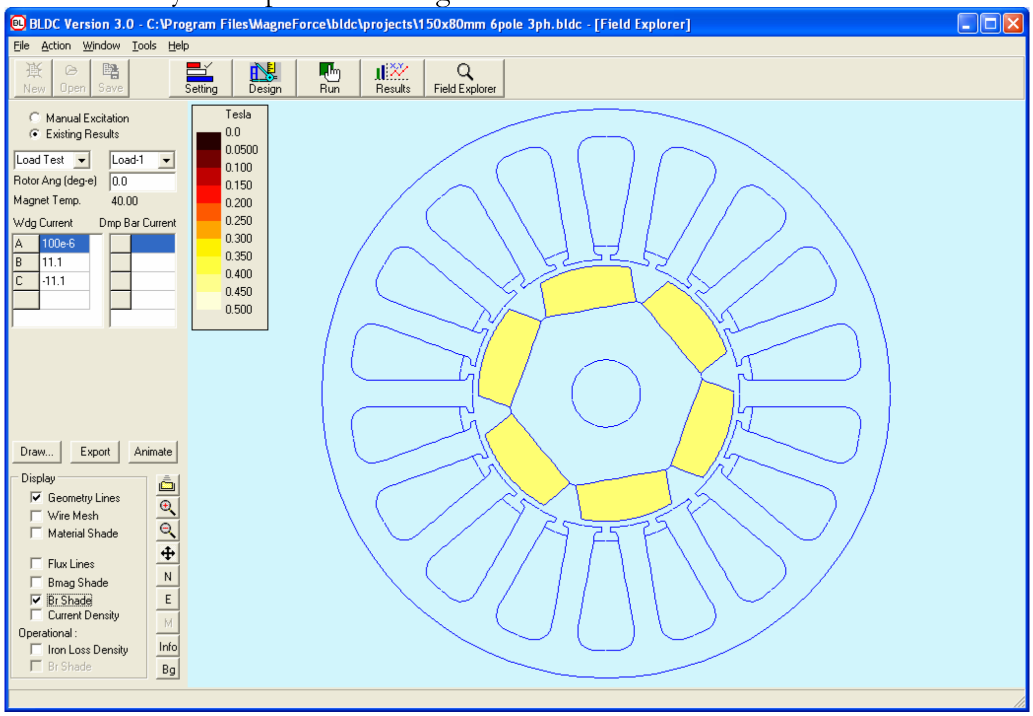
Under the Flux Lines option is the **Bmag Shade** check box that displays the magnetic flux density for this particular solution point along with a legend. The flux density is diplayed in Tesla.



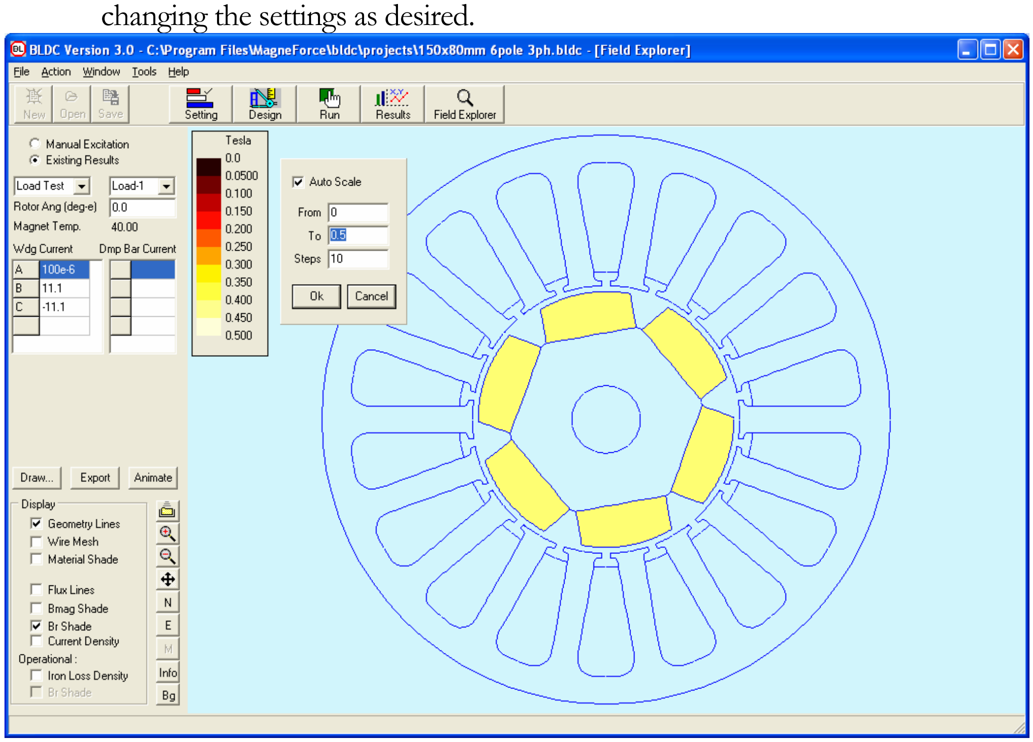
The scale of the flux density can be changed by double clicking the legend and changing the settings as desired.



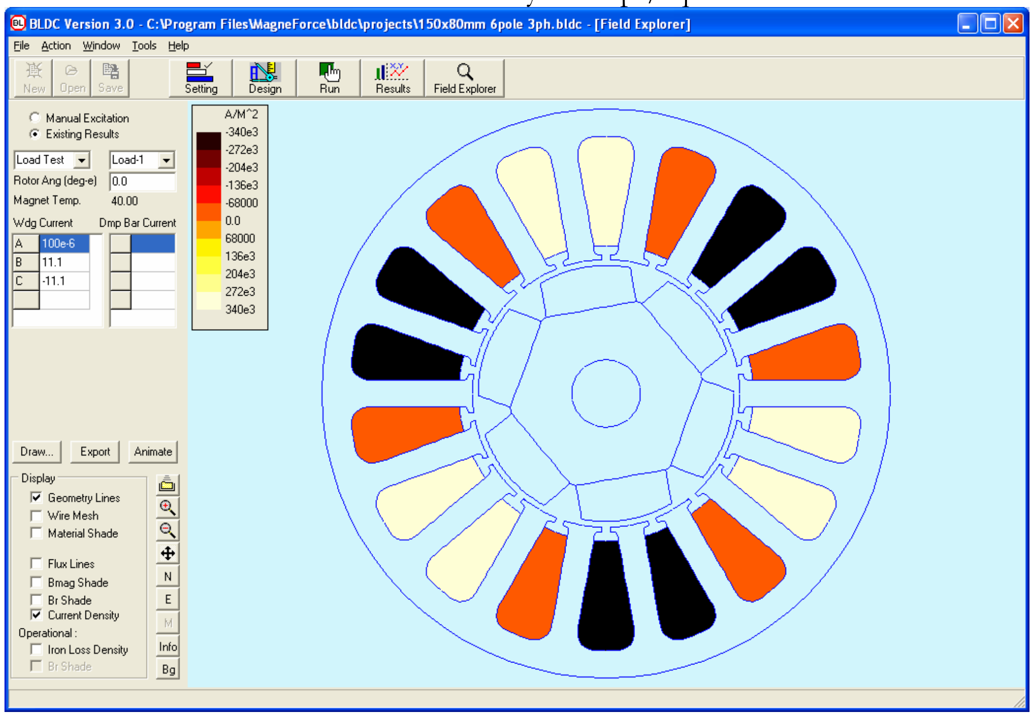
Br Shade is the next displayable parameter and when selected displays the flux density in the permanent magnets.



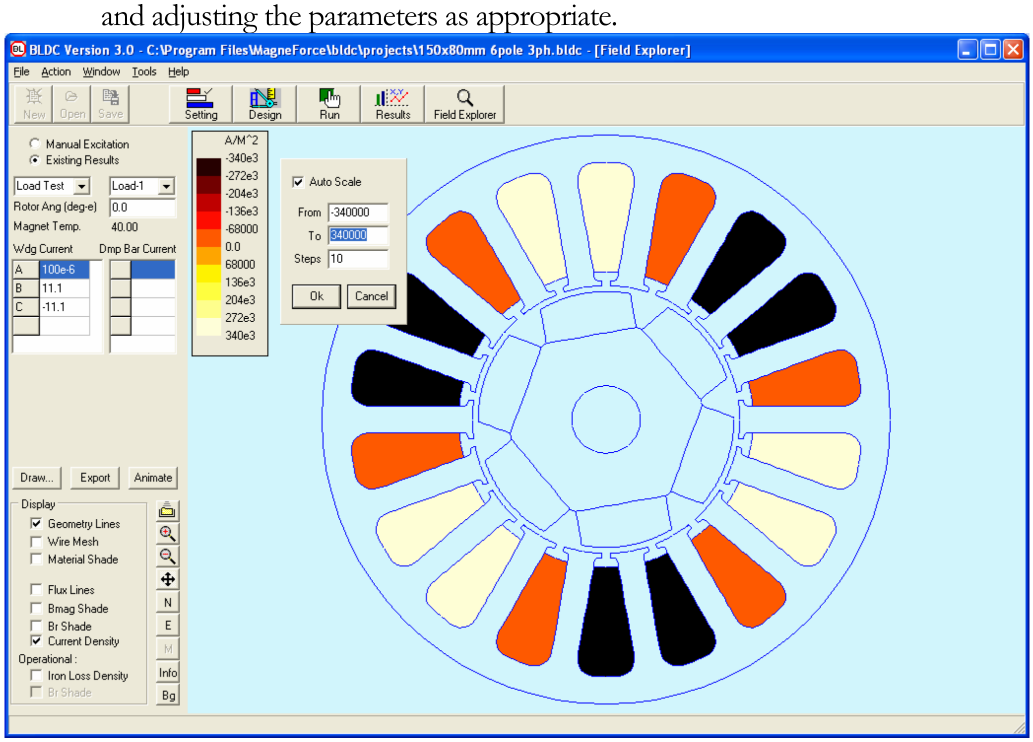
The scale of the flux density can be changed by double clicking the legend and changing the settings as desired.



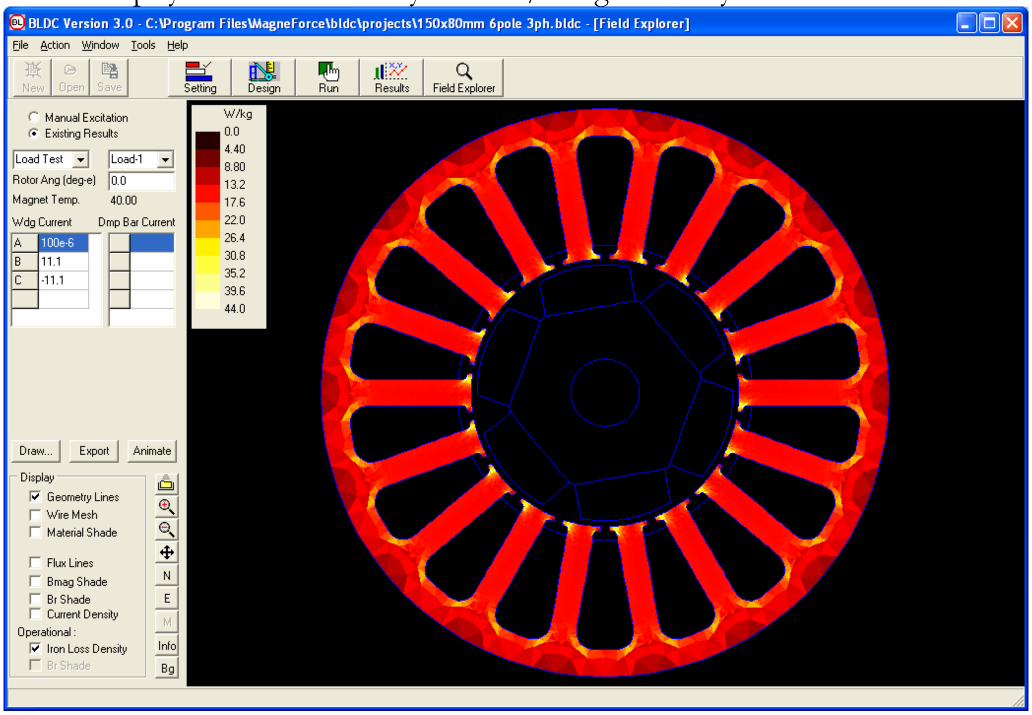
The next parameter that can be displayed is the **Current Density** which when selected will show the current density in Amps/square meter.



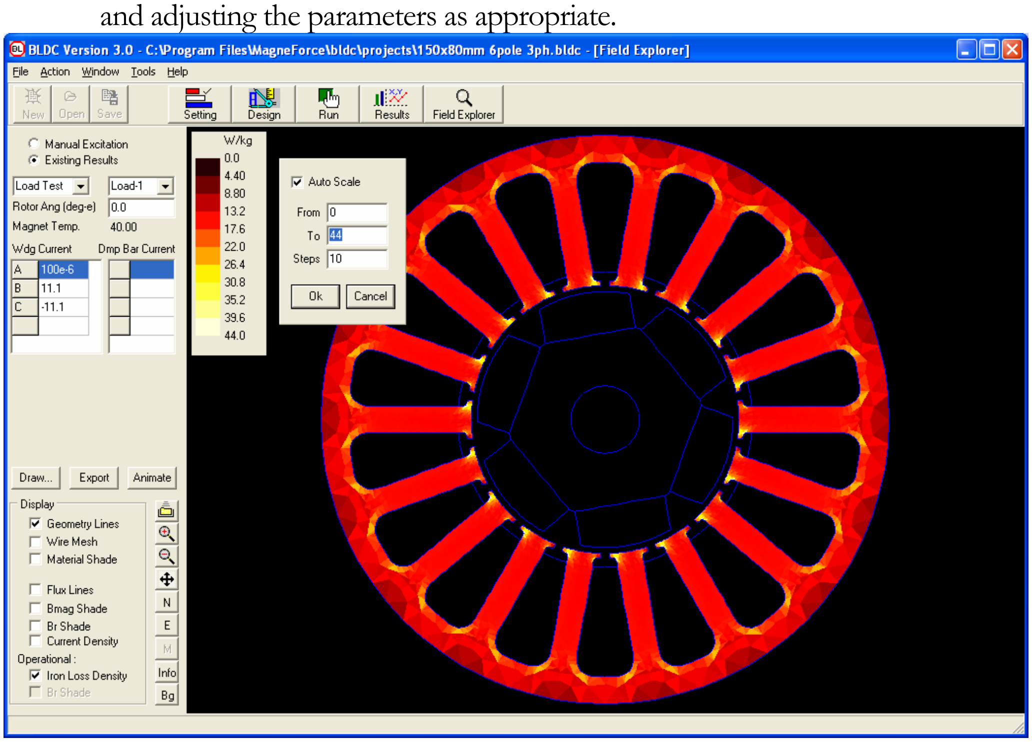
The scale of this parameter can also be adjusted by double clicking the legend and adjusting the parameters as appropriate.



The final parameter is the **Iron Loss Density** which when selected will display the iron loss density in Watts/Kilogram in any lamination material.

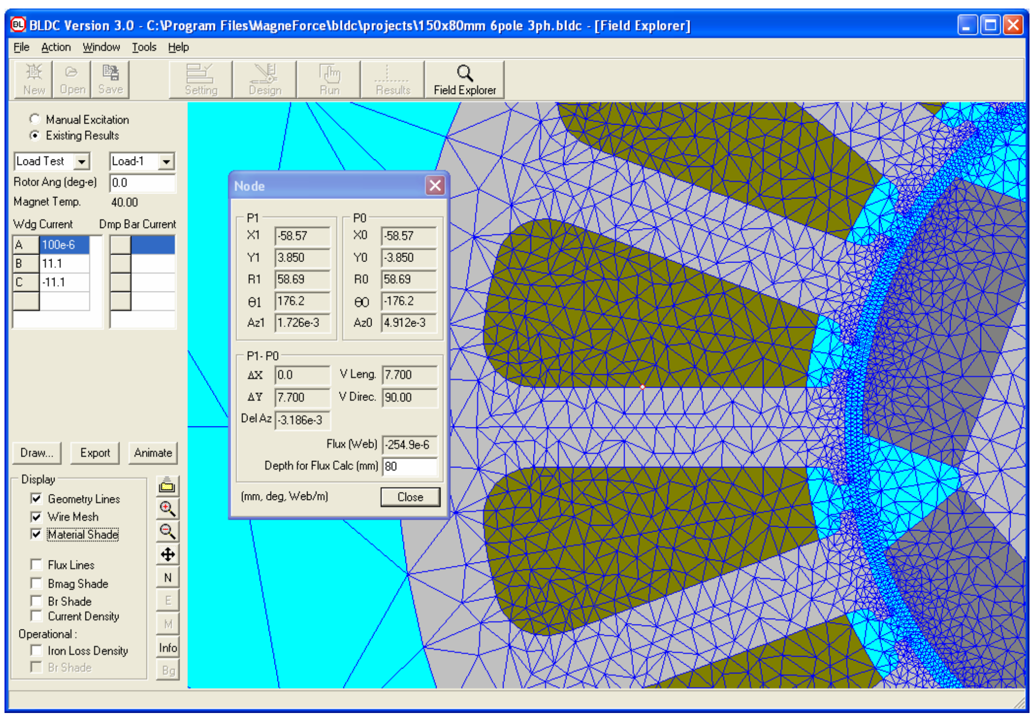


The scale of this parameter can also be adjusted by double clicking the legend and adjusting the parameters as appropriate.

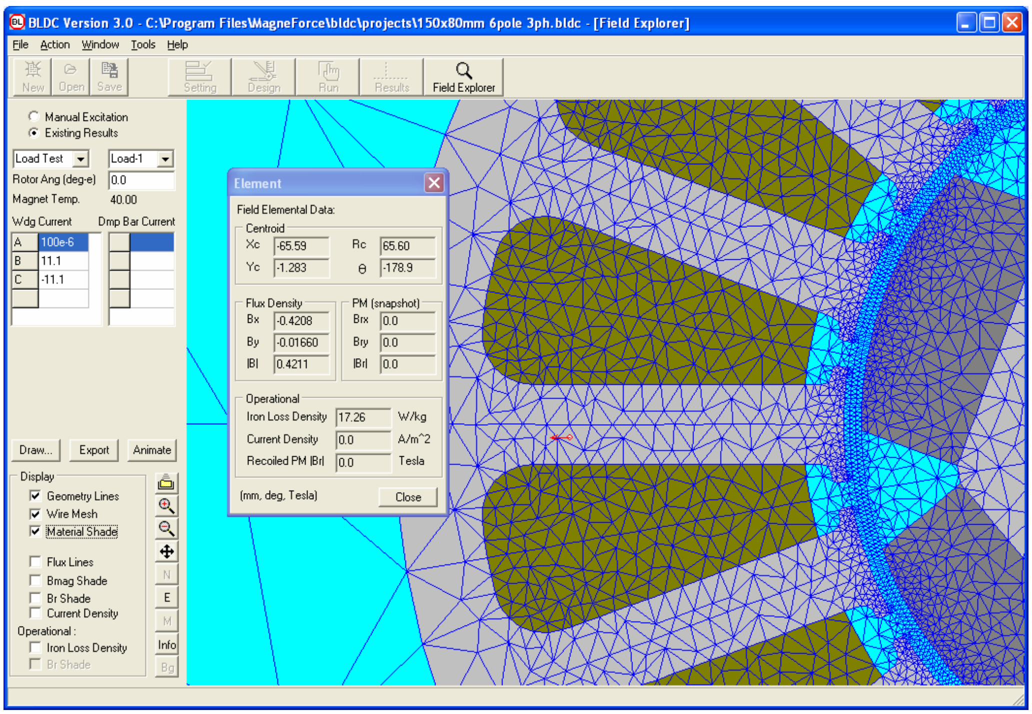


To the right of these check boxes are several sizing and information buttons. To zoom in on the image use the **Plus** button or to zoom out click the **Minus** button, to normalize the image size click the **Normalize** button or to shift the image click the **4-Arrows** button then move your cursor to the drawing area and click and drag the image the desired distance.

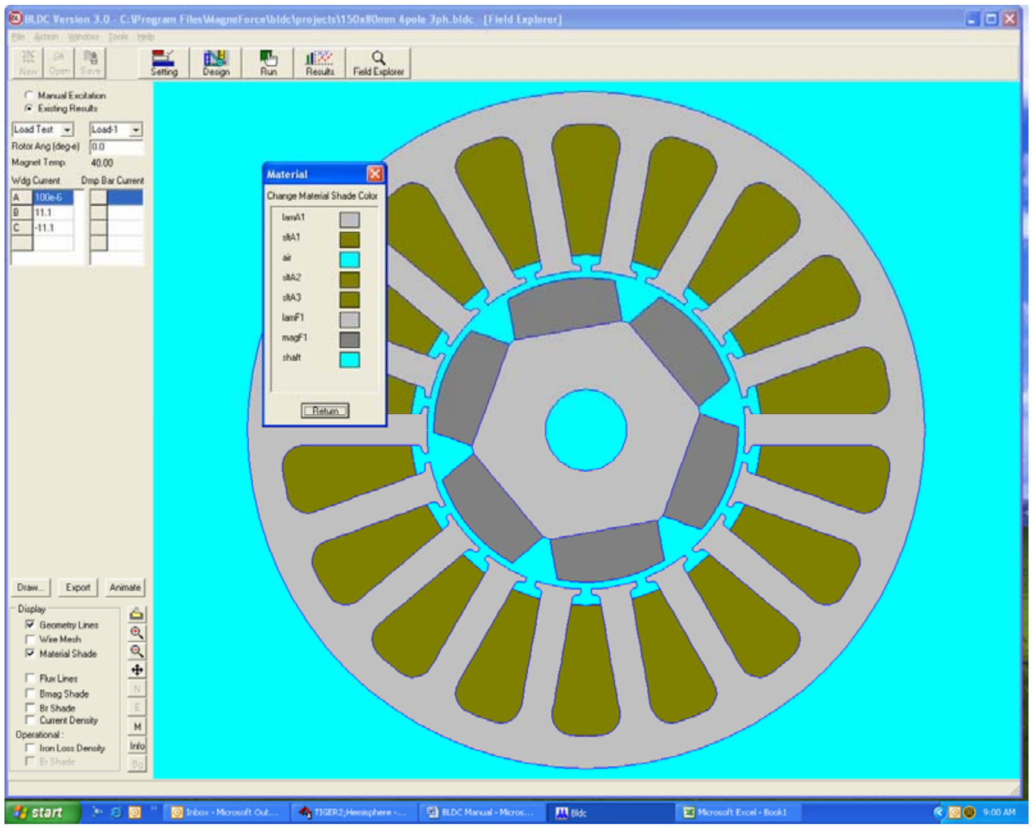
The button labeled **N** is the nodal button which when clicked displays information about the nodes. This button is most often used in conjunction with the wire mesh check box. An information box will be displayed that contains parameter information about two different nodes labeled **P0** and **P1** and you will be allowed to click on the wire mesh. The most recently clicked node is P1 and the node clicked just prior is P0. In the nodal information box the x, y, r, Theta and Az parameters are listed. Just below this is the differential information between P0 and P1. Listed here are Delta x, Delta y, Delta Az as well as the Vector Length and Direction. Below this is a Flux calculator that will give you the flux in Webers for a given depth between P1 and P0.



Under the nodal information button is a button labeled **E**, which is the elemental information button. This button is similar to the nodal information button, except that it displays information about the currently selected finite element. The centroid of the currently selected element is displayed both in x, y and r, theta coordinates. Below this is a listing of the elements flux density, including the Br values if the element lies within a permanent magnet. Under the Operational heading are several parameters that will be displayed if applicable to the selected element. For example if an element lies within a steel lamination it will have a corresponding **Iron Loss Density** value.

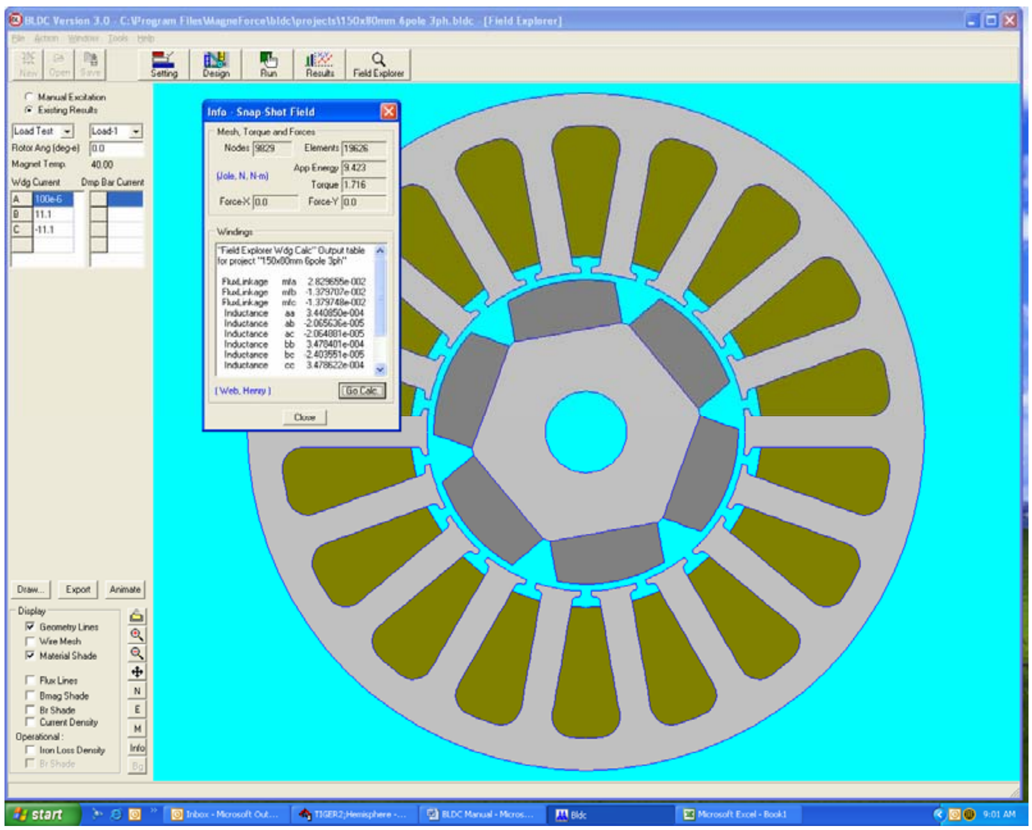


When the Material Shade checkbox is active the material button, represented by an **M**, is also activated. Clicking this button will allow you to change the color that each material type is displayed with. Each winding slot is treated as a separate material and as such can be assigned a distinct color, or you may wish to set all slots to the same color.

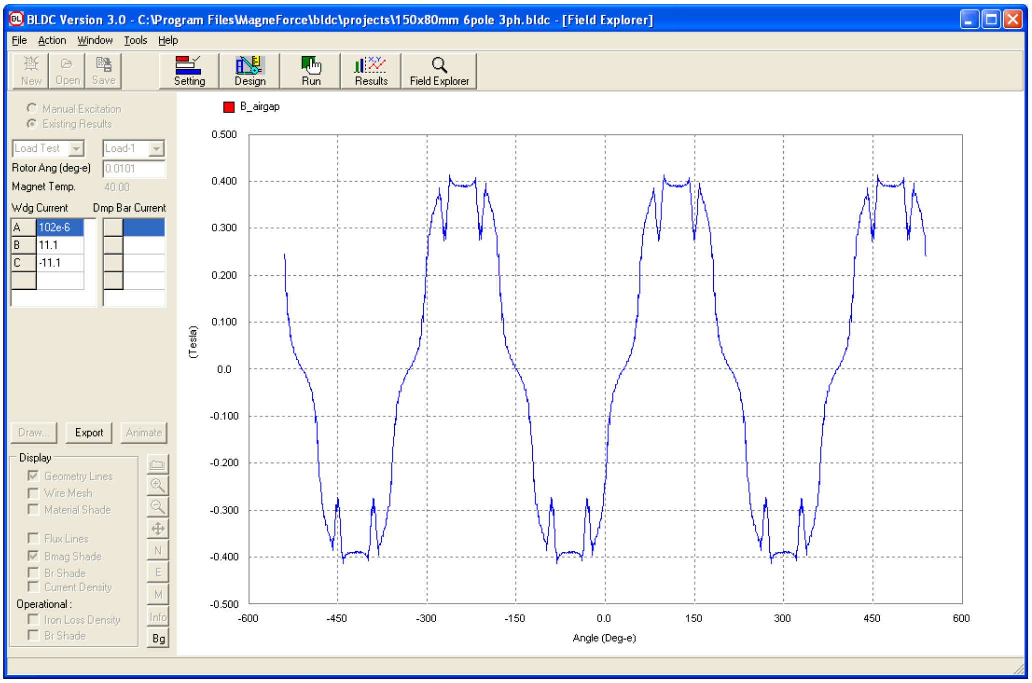


The next informational button is labeled **Info**. When clicked general finite element mesh information such as total number of nodes and elements is displayed. The remainder of the information displayed in this window is specific to the excitation and rotor angle that the machine is currently set to. The parameters displayed are the **Apparent Energy, Torque and the X and Y components of Force.**

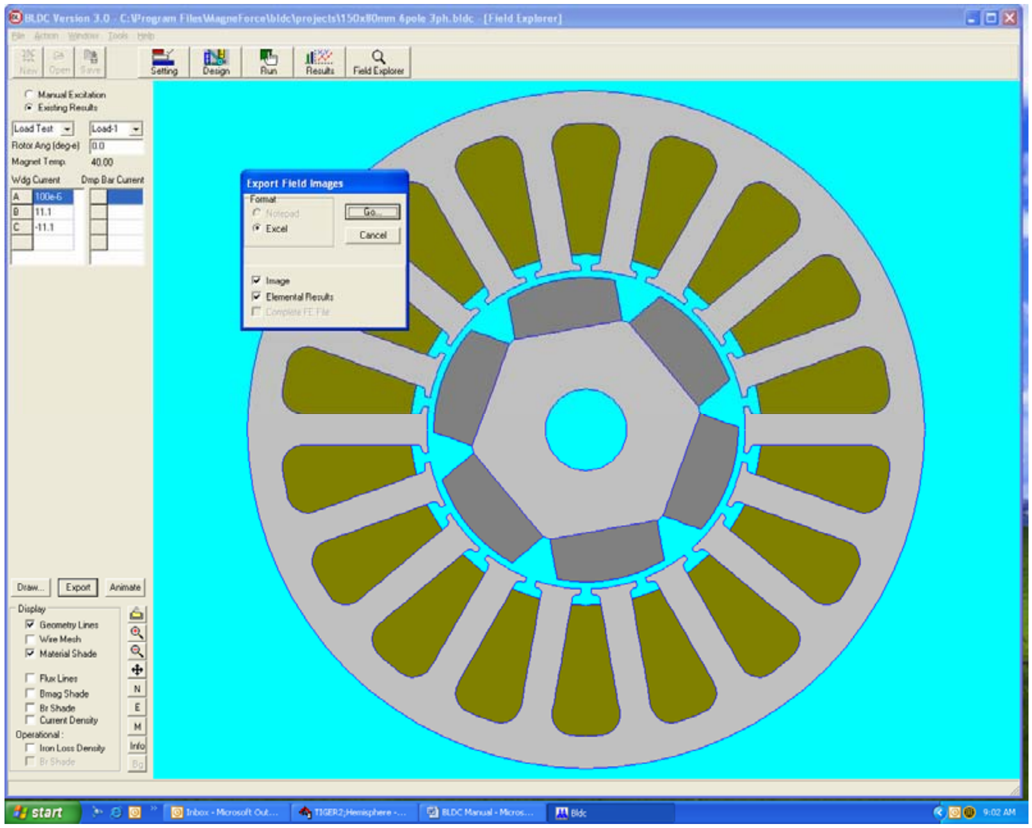
Snapshot winding information is available by clicking the **Go Calc** button in the lower right corner of this window. BLDC will calculate and display the instantaneous **Winding Flux Linkages, Inductances and Rotational EMF Coefficients**. When finished click the Close button.

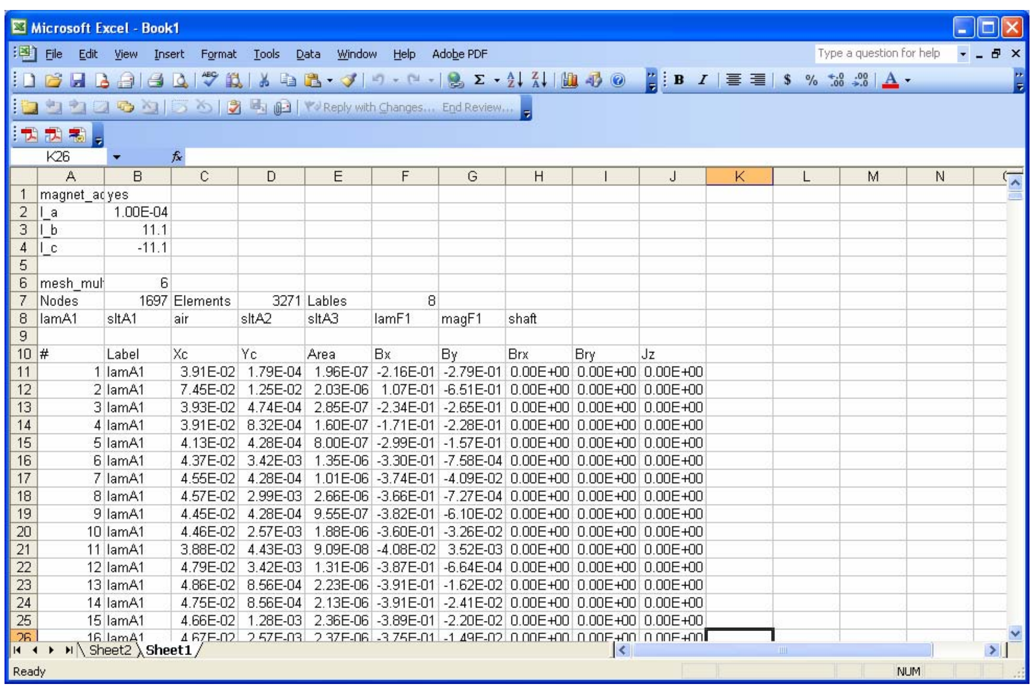


The final informational button is labeled **Bg**. Clicking this button will produce a plot of the mid-gap flux density in Webers vs Electrical Degrees, at the current rotor angle and excitation level. Click the **Bg** button again to return to the normal display.



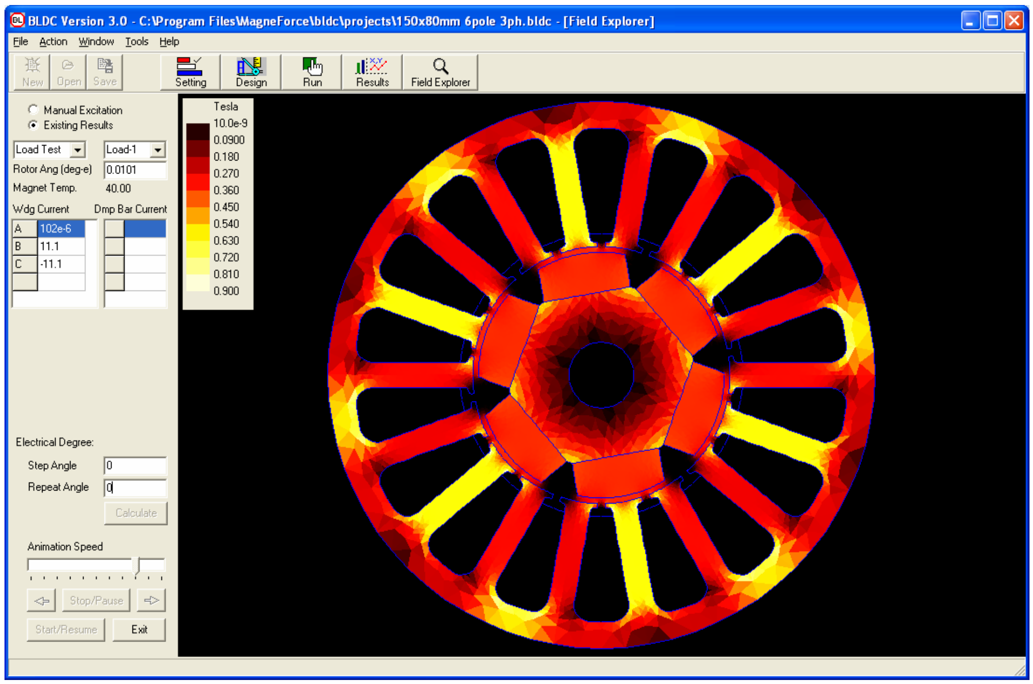
The **Export** button allows a number of parameters to be exported in Microsoft Excel format. The parameters that can be exported are the machine's cross sectional image and the complete finite element file.





	A	B	C	D	E	F	G	H	I	J
1	magnet_ac	yes								
2	I_a	1.00E-04								
3	I_b	11.1								
4	I_c	-11.1								
5										
6	mesh_mul	6								
7	Nodes	1697	Elements	3271	Lables	8				
8	lamA1	sltA1	air	sltA2	sltA3	lamF1	magF1	shaft		
9										
10	#	Label	Xc	Yc	Area	Bx	By	Brx	Bry	Jz
11	1	lamA1	3.91E-02	1.79E-04	1.96E-07	-2.16E-01	-2.79E-01	0.00E+00	0.00E+00	0.00E+00
12	2	lamA1	7.45E-02	1.25E-02	2.03E-06	1.07E-01	-6.51E-01	0.00E+00	0.00E+00	0.00E+00
13	3	lamA1	3.93E-02	4.74E-04	2.85E-07	-2.34E-01	-2.65E-01	0.00E+00	0.00E+00	0.00E+00
14	4	lamA1	3.91E-02	8.32E-04	1.60E-07	-1.71E-01	-2.28E-01	0.00E+00	0.00E+00	0.00E+00
15	5	lamA1	4.13E-02	4.28E-04	8.00E-07	-2.99E-01	-1.57E-01	0.00E+00	0.00E+00	0.00E+00
16	6	lamA1	4.37E-02	3.42E-03	1.35E-06	-3.30E-01	-7.58E-04	0.00E+00	0.00E+00	0.00E+00
17	7	lamA1	4.55E-02	4.28E-04	1.01E-06	-3.74E-01	-4.09E-02	0.00E+00	0.00E+00	0.00E+00
18	8	lamA1	4.57E-02	2.99E-03	2.66E-06	-3.66E-01	-7.27E-04	0.00E+00	0.00E+00	0.00E+00
19	9	lamA1	4.45E-02	4.28E-04	9.55E-07	-3.82E-01	-6.10E-02	0.00E+00	0.00E+00	0.00E+00
20	10	lamA1	4.46E-02	2.57E-03	1.88E-06	-3.60E-01	-3.26E-02	0.00E+00	0.00E+00	0.00E+00
21	11	lamA1	3.88E-02	4.43E-03	9.09E-08	-4.08E-02	3.52E-03	0.00E+00	0.00E+00	0.00E+00
22	12	lamA1	4.79E-02	3.42E-03	1.31E-06	-3.87E-01	-6.64E-04	0.00E+00	0.00E+00	0.00E+00
23	13	lamA1	4.86E-02	8.56E-04	2.23E-06	-3.91E-01	-1.62E-02	0.00E+00	0.00E+00	0.00E+00
24	14	lamA1	4.75E-02	8.56E-04	2.13E-06	-3.91E-01	-2.41E-02	0.00E+00	0.00E+00	0.00E+00
25	15	lamA1	4.66E-02	1.28E-03	2.36E-06	-3.89E-01	-2.20E-02	0.00E+00	0.00E+00	0.00E+00
26	16	lamA1	4.67E-02	2.57E-03	2.37E-06	-3.75E-01	-1.49E-02	0.00E+00	0.00E+00	0.00E+00

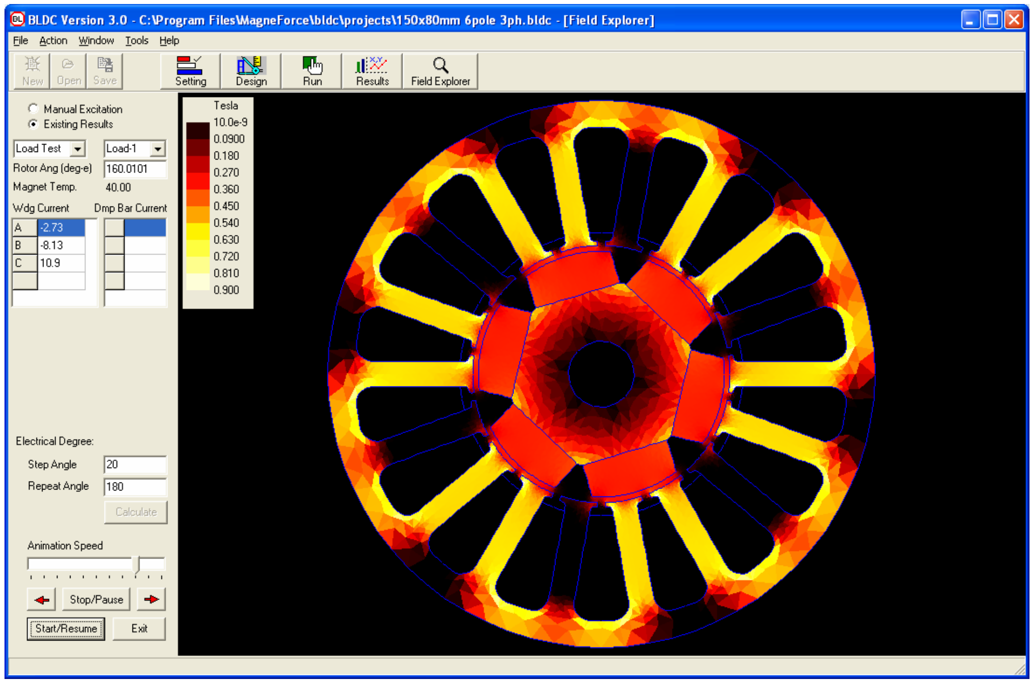
The **Animate** button allows you to see the field parameters in action as the machine would run. BLDC will step through a series of rotor positions and calculate the field parameter, flux density for example, at each position. You will then have the option of displaying these solutions one after another thereby forming an animation of a rotating machine. Clicking the **Animate** button will change the screen as below:



Input the following parameters:

- **Step Angle** is the increment between each rotor position solution point.
- **Repeat Angle** is the total angle that BLDC will calculate to. It will start at zero and calculate up to this point.

Once the two parameters have been entered click the **Calculate** button and BLDC will step through the desired positions calculating the field parameter chosen. Upon completion you will see the screen below:



Click the **Start/Resume** button to start and stop the animation being displayed. You may use the **Animation Speed** scroll bar to speed up or slow down the animation. You may also use the **Red Arrows** and the **Pause** button to step through each of the rotor positions manually. When finished viewing the animation click the **Exit** button to return to the normal field explorer display.